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The International Congress in London

Although these words are written during the run of the Congress, it is possible to state quite definitely that its success is assured. Ever since last Saturday, every hour has brought fresh delegates from practically every country in Europe, and nearly all the Dominions have a representative. The most disappointing feature is the smallness of the American delegation, unquestionably due to the European political tension, which distance probably magnifies. It appeared that the Italian delegation, too, would be small, but on Monday morning aeroplane and the Orient express brought about a dozen. France, Germany and the Scandinavian countries are very well represented, especially France, which includes a delegate from Morocco.

The garden party at Southward, Harrow, at which Mr. and Mrs. Barrington Hooper were the host and hostess, was an outstanding success, and it provided, under ideal conditions, the occasion for renewing and establishing cordial relations with our overseas guests. After the usual hesitancy, the guests soon settled down to indulge in the various games set out for their amusement. Mr. Lake and Mr. Lobstein, President of the French Association, expressed the indebtedness of the visitors for the hospitality shown to them.

The scene throughout Monday at the Registration office almost resembled a London railway terminus on a Bank Holiday Saturday, and it is to the credit of Mr. Makemson and his staff that the queues were dealt with with the expedition of the booking office clerk, despite the language difficulties.

The annual meeting of the Institute of British Foundrymen was severely businesslike. The election of Mr. D. H. Wood as the new Vice-President was enthusiastically endorsed, whilst the announcement that Mr. J. G. Pearce and Mr. E. J. Cooke were to receive the Oliver Stubbs Medal and the Meritorious Service Medal, respectively, was obviously very popular. The evening being free from any official functions, one heard of private parties being arranged for the informal entertainment of the overseas guests.

The Congress was officially opened on Tuesday morning by the Rt. Hon. the Lord Mayor of London, Sir Frank Bowater. It was particularly interesting that he should remark that the industry with which he was associated—that of paper and printing—was dependent for its success on foundry practice. It would be truthful to say that most industries are similarly placed. Dr. Guido Vanzetti, speaking in perfect English, replied to the address of welcome, stressing that patriotism and insistence on national economy were not bars, but should be aids to international technical co-operation, owing to the necessity for tackling problems from different angles. A corollary to this co-operation was an improvement in technique and the betterment of conditions of humanity. The Presidential Address was a real and authoritative contribution to the history of steel castings. It was particularly appropriate, as Mr. Lake's thesis was not confined to Britain or even to Europe, but ranged over the whole world. The second fiddle which the steel-foundry industry has had to play in the metallurgical orchestra is due in general to the fact that the average inventor was more impressed with the potentialities of the steel ingot business. With the exception of the pulverised fuel-fired rotary furnace, which was designed originally for iron melting, there has usually been modifications in design, or at least a distinct lapse of time, before adaptation of melting processes to steel castings. It is this factor which makes the collection of definite data so difficult. Even the most recent adaptations and inventions give rise to controversy because an experimental cast or series of casts must anticipate regular production.

The Fourth Edward Williams Lecture given by Prof. Bragg was of outstanding interest. We are sure it will be long before the world's foundrymen will forget the analogy of the disorderly car park as representing a mechanically strong alloy, as the individual cars cannot move, whereas an orderly arrangement of cars allows of easy dispersal. Again, the analogy of the parade ground and the fat and thin soldiers was a masterly example of his wonderful gift of making the abstruse subject of atomic patterns seem childishly simple. His lecture had another message, however, and that was a plea for the bridging of the gap between the University laboratory and industry. It is a gap not easily to be closed, for the two entities neither understand each other's objects nor do they speak the same language. Professor Bragg suggested the employment of trained physicists in the works laboratory, who would acquire a knowledge of manufacturing processes and so complete the link. Those in industry, however, realise that there are few organisations sufficiently large to carry anything other than a laboratory for control and immediate expansion purposes. They rely on the co-operative research associations for such help, and rightly or wrongly foundry owners will as a result of this lecture expect the appropriate organisations to act as their liaison with the great University and national laboratories. The example, dealt with at length by the Lecture, of the nickel iron aluminium magnet alloy showed very clearly how the latest scientific developments can help to a fundamental understanding of a particularly complex problem.

It must be obvious to everybody that the organisation of a congress planned on such ambitious lines as the one now approaching its close must have involved a tremendous effort on the part of the members of the two main organisation committees, despite the fact that the details of the programme have been handled by the permanent officials of the Institute. The preparation of the Papers, however, has largely been the task of this office, and we wish to thank our colleagues who have so willingly given up their leisure time to help in the translation and proof reading of such a mass of Papers.

The efforts of all, however, would have been abortive but for the sympathetic co-operation of His Majesty's Government, the civic authorities, the director of the National Physical Laboratory, the directorates of the various industrial enterprises in and around London, and the Worshipful Company of Barbers. So far as the London end is concerned, without being invidious, and risking the charge of being incomplete, we know that the special thanks of the members of the Congress are due to our new President, Mr. Lake; the immediate Past-President and the new President of the London Branch, Mr. C. C. Booth and Mr. Barrington Hooper; Mr. V. Delport, the honorary secretary of the London Committee, and Dr. A. B. Everest, who has guided the work of the Ladies' Committee. Finally, as we have stated above, it is by Mr. Makemson, whose organising genius we all so much admire, that the co-ordination of all our efforts has been brought to fruition with such success. To him we are sincerely grateful.

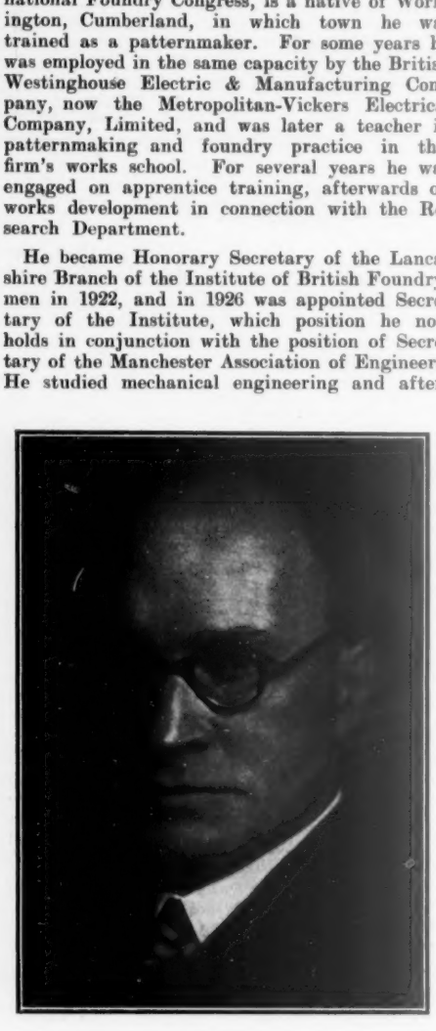
Contents

The International Congress in London	491
Mr. T. Makemson—Congress Secretary	492
Random Shots	492
Effect of Aluminium on Unalloyed Steels	492
Opening of Congress	493
The Government Reception at Lancaster House	495
Speeches at the Congress Banquet	496
The Garden Party	498
Mr. W. B. Lake's Presidential Address	499
I.B.F. Annual Meeting	501
Annual Report of the Institute of British Foundrymen	502
Seventh Annual Report of the Technical Committee	505
Atomic Patterns of Metals	506
A Selection of Congress Papers—	
Bonding Clays and the Properties of Synthetic Moulding Sands	509
The Thermal Conductivity of High-Duty and Alloy Cast Irons	513
Core-shop Control	516
Gating with Special Reference to the Optimum Flow Conditions in the Molten Metal	519
Some Iron Castings for Steelworks Plant	521
Light-Alloy Melting Practice	526
The Effect of Melting Conditions on Light Alloys	528
Solution Heat-Treatment of Aluminium Casting Alloys	531
Pressure Die-Casting in Aluminium- and Zinc-Base Alloys	535
Properties of Quenching Oils	542
Correspondence	542
World's Largest Ingot Mould	542
The Week's News in Brief	543
Trade Talk	543
Applications for Trade Marks	543
Personal	543
Company Reports	543
Obituary	543
Patent Specifications Accepted	543
Forthcoming Event	543
Raw Material Markets	544
Contracts Open	544

Mr. T. Makemson—Congress Secretary

Mr. T. Makemson, Secretary of the International Foundry Congress, is a native of Workington, Cumberland, in which town he was trained as a patternmaker. For some years he was employed in the same capacity by the British Westinghouse Electric & Manufacturing Company, now the Metropolitan-Vickers Electrical Company, Limited, and was later a teacher in patternmaking and foundry practice in this firm's works school. For several years he was engaged on apprentice training, afterwards on works development in connection with the Research Department.

He became Honorary Secretary of the Lancashire Branch of the Institute of British Foundrymen in 1922, and in 1926 was appointed Secretary of the Institute, which position he now holds in conjunction with the position of Secretary of the Manchester Association of Engineers. He studied mechanical engineering and afterwards took the full course in metallurgy at the College of Technology, Manchester, and holds a diploma of the Associate of the College.



MR. T. MAKEMSON.

He is Secretary of the City and Guilds Advisory Committee on Foundry Practice and Patternmaking, and was joint examiner for four years. In addition, he is a member of the Council of the British Cast Iron Research Association; member of the Joint Committee on Materials and Testing; member of the Engineering Sub-Committee on the National Register—Ministry of Labour; member of the Sheffield University Advisory Committee on Foundry Courses; and a special lecturer of the British Foundry School. He has been Honorary Secretary of the International Committee of Foundry Technical Associations since its establishment in 1926, and has travelled extensively in this capacity.

APPRENTICES of the Tees-side Bridge & Engineering Works, Limited, Middlesbrough, who came out on strike last week, resumed work on Monday after a settlement had been reached between the works management and officials of the Amalgamated Engineering Union.

Random Shots

The garden party which marked the unofficial opening of the International Congress on Sunday afternoon was an event both characteristically human and characteristically English. To entertain at all is a trait peculiar to the human race, for whoever heard of lions (other than human ones) asking each other to their dens, or yet of skylarks skylarking by mutual invitation in one another's nests? In fact, it has been said that mankind can be divided into two great classes—hosts (whose primary impulse is to offer hospitality) and guests (with an unfailing instinct to accept hospitality). Everyone knows that Mr. Barrington Hooper belongs outstandingly to the former class, and the guests who accepted on this occasion were happy to belong to the latter division!

* * *

The weather, of course, was characteristically English, with bright, hot sunshine alternating with threats of showers. It even kept a few guests away, unaccustomed as people from better climes are to such uncertainties, but the English visitors turned up in full force, for, as Mr. Hooper pointed out, if we in England waited for perfect weather, we should never get anything done!

* * *

The garden, too, is one which anyone would be proud to show to his guests, whatever country they come from. Far from being characteristically English, it is, in fact, an almost perfect example of the English garden as it should be, with its smooth lawns, its herbaceous borders, its corner set aside as a kitchen garden and, above all, its dedication to games of every description. Mr. Hooper is justly proud of his garden, for he puts a great deal of personal thought and actual work into it, and with him it is indeed a real labour of love.

* * *

Sunday's function was a quietly dignified affair, much like the first half-hour of a children's party. The day spent in going to Windsor on Sunday will be like the last half-hour of the same party, the excitement of which rises in a gradual crescendo (throughout the week in this case), culminating in a wild hilarity towards the end, with all the guests trying hard not to show how desperately tired out they are!

* * *

It was gratifying to hear that the Italian delegates were so keen to come to the Congress that, in spite of monetary difficulties, they had all their bags packed in readiness. The necessary "valuta" arrived at the last moment, however, whereupon they snatched up their bags and boarded a plane, arriving in London on Sunday night.

* * *

The Congress is creating a record in many directions. Not only are there upwards of 600 delegates present, the greatest number ever registered for any previous Congress, but they include representatives from 24 different countries, and eleven Past-Presidents have turned up to do their stuff.

* * *

There is a recurring legend on the printed programme which reads "evening free," but so far no one has found a free moment, for the number of private parties that are being held seems without end. One dashes from one cocktail party to dinner with someone else, and even the interval before the Government reception was used for private hospitality. It was a specially charming gesture on the part of M. Lobstein, the President of the French Foundry Technical Association, thus to entertain some of the prominent officials of the Institute.

* * *

At that dinner M. Lobstein told an amusing little story of his early difficulties with the English language (which, by the way, he has since mastered exceedingly well). Staying at an English hotel for the first time, he was surprised each morning by the maid who came and asked if he would like a bath. Thinking she was commenting on the weather (how did he guess that very English tendency?), he replied each morning that it was a very nice day. On the third day he said to his friend that he really would like a bath, and how was he to ask for it, whereupon his friend rang for the chambermaid. "But, sir," she replied to his remonstration, "I have prepared the bath two mornings running for monsieur, but he has never taken it."

* * *

Seeing Mr. James Bell, who is the father of triplets, at the Government reception brought back a reminder of a good story told by an engineer against himself. His wife presented him with a daughter, which was followed a year or two later by a son. The father was very proud of his pigeon pair, and told his friends that now that he had a sample of each, he could start on real production!

* * *

At the conclusion of the American Foundrymen's Association's Annual Convention, Mr. J. E. Hurst organised his own post-Congress tour. He was honoured with an invitation from the Birmingham (Alabama) Chapter to address them. The notice convening the meeting states that "Dr. Hurst of England" will be the next lecturer. He is introduced as "Dr. J. E. (Jimmie) Hurst," and after setting forth his achievements in a nutshell, he is summed up as a "damn good fellow."

"MARKSMAN."

Effect of Aluminium on Unalloyed Steels

E. HOUDREMONT and H. SCHRADER, in a recent issue of "Archiv für das Eisenhüttenwesen," have examined the influence of varying amounts of aluminium on the properties of a range of carbon steels. Aluminium contents up to 2.5 per cent. were used, and it was found that increase of aluminium in this range gradually raised the temperature of the A, transformation, particularly in low-carbon steels. The effect of aluminium on depth hardening, overheating characteristics, and sensitivity to cracking were also examined, and it was concluded that two overlapping tendencies were operative. The first of these was the effect of small aluminium additions in producing an inherently fine grain in the steel which reduces depth hardening and retards overheating and the incidence of quenching cracks. With higher aluminium contents this effect is overweighted by the pure alloying effect of the aluminium which reverses all these tendencies. An interesting section of the Paper examines the reason for the grain control exercised by small amounts of aluminium. Identical melts made under *vacuo*, and in atmospheres of nitrogen and air, were examined for inherent grain size and overheating characteristics. It was concluded that the grain growth inhibiting properties induced by aluminium were due to the formation of aluminium nitride. Rate of decarburisation was found to be slowest in fine grained steels, due to the slowness with which carbide diffused to the surface. In magnetic tests no evidence was found for the existence of a complex carbide containing aluminium, and if such a compound does exist, it must be in steels containing more aluminium than those investigated in the present work.

Opening Session of the International Congress in London

The International Foundry Congress was opened officially on Tuesday morning, June 13, at the Dorchester Hotel, by the Rt. Hon. the Lord Mayor of London (Sir Frank Bowater, Kt.). The Lord Mayor was received by the retiring President (Mr. J. Hepworth, J.P., M.P.), who presided, and was accompanied on the platform by Mr. W. B. Lake, J.P. (President-Elect), Major R. Miles and Mr. D. H. Wood (Vice-Presidents), Dr. Guido Vanzetti, of Italy (President, International Committee of Foundry Technical Associations), Mr. C. W. Bigg (Past-President), and Mr. S. H. Russell (Past-President and Hon. Treasurer).

Civic Welcome

The LORD MAYOR, opening the Congress, said it was devoted to the promotion of scientific development and the improvement of the technique of the foundry industry. It was surprising to him to learn, however, that in addition to some 400 foundrymen resident in this country, the Congress would be attended by probably 200 overseas delegates from several European countries, from the British Dominions and from the United States. He congratulated all concerned with the organisation of so vast a gathering.

He imagined that the Congress shouldered responsibilities as never before in these days of intensive work in all that had to do with the foundryman's craft. Commenting on the fact that exactly ten years had elapsed since the Congress had last met in London, he said he felt sure that now, as then, the delegates would find much that would give them pleasure, quite apart from their deliberations and work well done.

Having recalled Kipling's reference to gold, silver and copper, but iron, cold iron, as the master of them all, the Lord Mayor said that one often heard the statement "Iron entered his soul." But he ventured to suggest that the very essence of the intelligence and skill of the delegates went into the work of the foundry, ever seeking the aid of modern science and ingenuity, so that their craftsmanship might go from standard to standard, from success to success.

He believed that in certain directions and branches of the craft even to-day, with every modern scientific invention, with the great knowledge of the modern chemist, we were still unable to excel the craftsmanship of the ancients.

In his business life, long since closed, he had realised all that he and his family had owed to the work of the founders, more especially the type founders, for their success and prosperity. Therefore, he was particularly happy to be associated with the gathering, and had great pleasure in declaring it open.

Reply on Behalf of Overseas Delegates

DR. GUIDO VANZETTI, of Italy (President, International Committee of Foundry Technical Associations), expressed thanks on behalf of the overseas delegates for the warm hospitality and welcome extended to them. The words with which the Lord Mayor had welcomed them, he said, were full of understanding for their efforts and their faith in the scientific and practical aims they had set before them.

Changing as they did every year the venue of their meetings, they were naturally rather inclined to compare their reactions in distant and different capitals; but, without in any way impairing their admiration and gratitude for any other country, rarely had their spirit been so uplifted as in the capital of the vast British Empire, where the work of five continents seemed to re-echo. They met again with the certainty that this time also those sincere and deep exchanges of views, that mutual incitement to competition and victory, would do a great deal of good not only to their art and profession, but also to the evolution of science and to the progress of industry.

People in the most progressive countries had realised that there could not be a large industry capable of reaching sure and practical results and adequate to the needs of our times, if it were not based on scientific knowledge and experience; industry and science had become so entwined that there was no industrial works which had not, as an indispensable branch, a research and routine laboratory, and there was not a scientist who did not aim to effect practical application of his inventions and discoveries, even when they appeared to be constricted to the realm of pure abstract research.

Whilst he had the honour to represent the foundrymen of the various countries invited to the Congress, he could not forget that he was first an Italian. Thus, he was led to recall the names of two great Italians, who for their genius belonged to all humanity. Leonardo da Vinci, although one of the greatest idealists and one of the most venturesome theorists the world had ever produced, had always aimed at something practical to humanity, and had written "Remember that each proposition must possess basic utility in order that such knowledge might not be useless." Guglielmo Marconi, also an Italian, was particularly loved and appreciated in England; although he had reached the highest limits of scientific abstraction, he had always applied his inventions to such humanitarian purposes that they almost appeared as the acts of a magnanimous benefactor.

But just because to-day industry and science were associated in a common work, both science and industry needed a constant exchange of ideas and information on their efforts and on their results. By means of periodical meetings it was exactly the intention to avoid the overlapping and waste due to individualism, which was a real calamity for science and industry.

The awakening of new national energies, the necessity for co-ordinating the material forces of each single people, the decisive tendency to be masters of their own destinies, had given rise, in many nations, to the problem of self-sufficiency. But that did not prevent industrialists—inasmuch as they were trying to make working conditions more rapid and less heavy, to make them more efficient, more perfect and more economic—from sharing the knowledge of their efforts and of the results achieved.

Each one of them in his heart was first of all a good patriot, endeavouring to lead his country and his particular industry to the forefront; that aim incited him continuously to improve his work. But the periodical meetings and the friendly ties and mutual respect derived from them served more than anything else the cause of progress and universal peace. There could be no diffidence, hostility or jealousy in their field of action, where theory had to illuminate practice and where both aimed at making man more firmly master of the laws of nature and of his possibilities of dominating those laws and subjecting them to his will. On the other hand, a common pride and joy united them to-day, as in the past, in the knowledge that they were at the head of that movement which left nothing to chance that was connected with human work, which wanted everything done according to the law of the minimum effort with the maximum of results, so that industry would be able to supply the increasingly complex needs of human society.

They trusted that God would assist the men who were devoting themselves to that immense task in order to give industry, and thus all mankind, an era of prosperity, of stability and of peace.

MR. W. B. LAKE, J.P.
(President of the Congress.)

Presentation of Medals

On behalf of the Institute of British Foundrymen, the Lord Mayor presented medals.

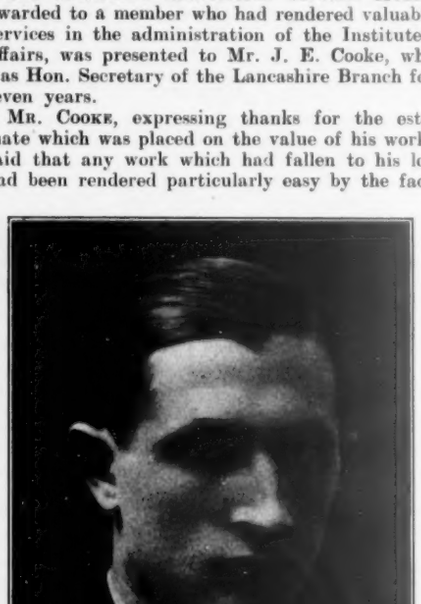
The Oliver Stubbs Gold Medal, awarded annually to a member of the Institute who had rendered distinguished services to the Institute and to the ideals it represented, was presented to Mr. J. G. Pearce (Director of the British Cast Iron Research Association).

MR. PEARCE, in his response, said he received the medal with pride and pleasure for many reasons, but for three in particular. First, it was associated with the name of Oliver Stubbs, whom he always recalled with affectionate regard and who was a great friend to the

Institute and to the British Cast Iron Research Association. Secondly, the award he accepted as a tribute to the work of the Association during the past 15 years, and not so much to himself personally as to the staff, from whom he had had the most loyal help. Thirdly, it was a token and an earnest of the co-operation which should exist between the two bodies and which it would always be his earnest desire to forward as far as lay within his power.

The Institute's Meritorious Services Medal, awarded to a member who had rendered valuable services in the administration of the Institute's affairs, was presented to Mr. J. E. Cooke, who was Hon. Secretary of the Lancashire Branch for seven years.

MR. COOKE, expressing thanks for the estimate which was placed on the value of his work, said that any work which had fallen to his lot had been rendered particularly easy by the fact



DR. GUIDO VANZETTI
(President of the International Committee of Foundry Technical Associations).

that behind him in the Lancashire Branch he had always had an extremely loyal group of fellow workers.

The E. J. Fox Gold Medal, awarded annually to a person of any nationality who was distinguished in foundry practice and science and in metallurgy, was presented to Dr. H. A. Schwartz, of Cleveland, Ohio, U.S.A., esteemed throughout the world for his scientific work in the development of malleable cast iron.

DR. SCHWARTZ, expressing his great appreciation, said that the Institute had established the calibre of the E. J. Fox Medal when it had made the first award to Prof T. Turner; and he recalled that the first European name which appeared among the American Foundrymen's Association medallists was also that of Prof. Turner. Dr. Schwartz paid tribute to all concerned with the work with which his name was associated—the Corporation which had for 37 years financed the research work at considerable expense; his associates in the Research Department and those in the plants of the company who had attempted to utilise those things which the research workers tried to make available to them; and lastly, a considerable body of undergraduate and graduate students who had done a considerable amount of theoretical scientific exploration.

Vote of Thanks to the Lord Mayor

The PRESIDENT, proposing a vote of thanks to the Lord Mayor for having attended to open the Congress, said that his office as first citizen of the largest city in the world signified many things, the first and foremost being service—service to the City and to the State. The name of Bowater stood out in large letters by reason of the service which bearers of that name had rendered to the City and the State; and all were grateful to him for his service and for his gracious presence at the opening of the Congress.

MR. W. B. LAKE, J.P. (President-Elect), seconding, recalled that ten years ago the Congress had received very great help from the City of London, and it was again greatly indebted to the Lord Mayor for his kindness in opening the 1939 Congress.

The vote of thanks was carried with enthusiasm.

The LORD MAYOR, in his response, said he trusted that the Congress would be very happy and successful.

Induction of New President

MR. LAKE was inducted into the chair and was invested with the Presidential chain by Mr. Hepworth, who commented upon the distinction of being elected President at the time of the International Congress, and Mr. Lake's worthiness to uphold the traditions of the Institute. He wished both Mr. and Mrs. Lake happiness, health and prosperity during the coming year and for many years to come. Mr. Lake expressed his gratitude.

Presentation of Badges

A Past-President's badge was formally presented to Mr. Hepworth as a token of his Presidency and the services he had rendered during the past year. Mr. Lake expressed the hope that Mr. Hepworth would always retain happy memories of his year of office.

The collarette and badge worn by the President's wife was presented by Mrs. Hepworth to Mrs. Lake, the former confessing, amid laughter, that she was sorry to part with it. She wished Mrs. Lake health and happiness. Mrs. Lake responded.

Vice-Presidents' badges were presented to Major R. Miles (Middlesbrough Branch) and to Mr. D. H. Wood (Birmingham Branch), both of whom voiced their sense of privilege in being able to render service to the Institute.

A Loyal Message to Their Majesties

On the motion of the PRESIDENT, seconded by MR. HEPWORTH, the meeting heartily agreed that a message of greeting and loyalty be sent to Their Majesties the King and Queen.

Welcome to Overseas Delegates

The PRESIDENT, extending a hearty welcome to friends from overseas who were attending the Congress, said he thanked them for coming; their British colleagues were delighted to see them, and would do everything possible to make their visit happy and profitable. He added the wish, which would be echoed by all British foundrymen, that all the nations of the world might come together with the same cordiality and friendliness as did the foundrymen of the various nations, and that they might all work together for peace and for the benefit of humanity.

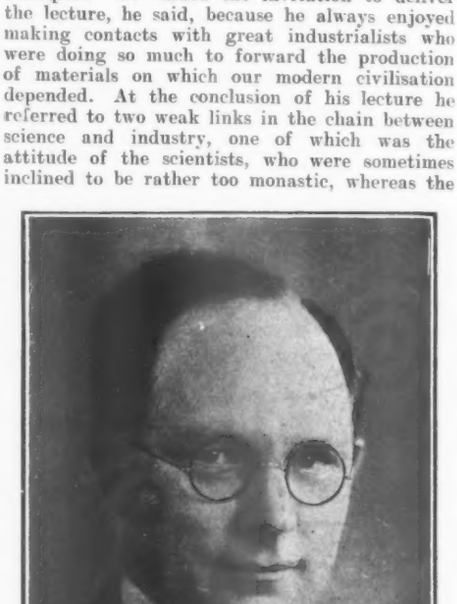
Presidential Address

The PRESIDENT then delivered his Address, in which he dealt with the history of steel castings, which have been one of the major interests of his career. The full text of his Address is given on page 499.

Following the Address, MR. HEPWORTH voiced the thanks of the meeting to Mr. Lake, and endorsed his reference to the desire for peace. If there could be more conferences of the nature of that in which the foundrymen were participating, he said, we should arrive at a solution of our problems. The President, he said, was a pioneer in the foundry industry, and it was that type of man whom the Institute desired to elect to the Presidency. The Address had also demonstrated that the progress which had been made in the industry had been made by close collaboration between the various nations.

The Edward Williams Lecture

PROF. W. L. BRAGG, O.B.E., D.Sc., M.A., F.R.S., Nobel Laureate (Director, Cavendish Laboratory, University of Cambridge), delivered the fourth Edward Williams Lecture (reproduced in full on pages 506-8 of this issue), in which he discussed the study of the atomic patterns of metals, a work with which he has been intimately associated for many years. He put forward a highly scientific subject in a most understandable way, illustrating the disposition of atoms in a crystal of metal by homely examples. He valued the invitation to deliver the lecture, he said, because he always enjoyed making contacts with great industrialists who were doing so much to forward the production of materials on which our modern civilisation depended. At the conclusion of his lecture he referred to two weak links in the chain between science and industry, one of which was the attitude of the scientists, who were sometimes inclined to be rather too monastic, whereas the



MR. J. G. PEARCE, M.Sc., M.I.E.E., F.INST.P.
(Awarded the Oliver Stubbs Gold Medal).

other was that industries in this country had not nearly enough men who, whilst looking at everything from the industrial point of view, could at the same time talk the scientists' language. He was always anxious to try to forge those links a little stronger.

MR. C. W. BIGG (Past-President), proposing a vote of thanks to Professor Bragg, assured him that there was no organisation in the country or in the world that was more anxious to strengthen the link between science and industry than was the Institute of British Foundrymen. The members were greatly appreciative of the honour Professor Bragg had done them in delivering the lecture, which alone was sufficient to mark the 1939 Congress as an event of very great importance in its contribution to the most advanced metallurgical knowledge.

MR. V. STOBIE (Past-President), seconding, expressed gratitude for the truly deep information which Professor Bragg had given in his lecture and for having honoured the Institute so early in a new series of lecture.

Commenting on a reference by Professor Bragg in connection with the ductility of a pure crystal of cadmium, that we progressed because we were muddlers, Mr. Stobie said there seemed to be a lot in being organised muddlers; and if industrialists secured the help of Professor Bragg and his confrères, so that the latter could show how the muddlers could be still greater muddlers and could produce still better materials, they would be very happy.

The vote of thanks was accorded enthusiastically, and the Congress then adjourned for luncheon.

The Government Reception at Lancaster House

It was a particularly happy circumstance, in view of the international character of the Congress, that at the invitation of His Majesty's Government, and at a comparatively early stage in the week's proceedings, the delegates had the opportunity of meeting each other in an informal atmosphere, on Tuesday evening, June 13, at Lancaster House, just behind St. James's Palace.

There they were received by the Lord President of the Council (the Right Honourable Viscount Runciman, P.C.) and Viscountess Runciman. And subsequently, whilst walking around among the interesting relics exhibited there of the early and recent history of London, to the accompaniment of light music by instrumentalists of H.M. Scots Guards, they made full use of the opportunities of making acquaintances and cementing further those that had been made in former years and during the first three days of the Congress week. Foundrymen are good mixers at any time, but in such circumstances as prevailed at the reception, attended by so many having common interests, there could be no question of the lasting value of that function.

Viscount and Viscountess Runciman spent some time in conversation with their guests during their inspection of the museum; and in the refreshment room one noted many groups of British and overseas delegates in earnest discussion of many metallurgical and foundry problems, the sort of conversations which inevitably result in the "swopping" of practical experiences and tips which can be utilised in practice to mutual advantage. So that, both from the social and the technical points of view, the function was most valuable.

The guests present at the reception included Lord Stamp (President, London Midland & Scottish Railway) and the Czecho-Slovakian Chargé d'Affaires.

Lancaster House, which was originally known as York House, and was the residence of the Duke of York (second son of George III), was acquired in 1912 by the then Sir W. H. Lever (who later became Lord Leverhulme), who presented it to the nation as a home for the London Museum. It is notable for its grand staircase. The Museum was founded in 1911, to commemorate the Coronation of King George V, and illustrates London and London life from prehistoric times. There is a profusion of delicate examples of china ware; and many of the ladies were absorbed in the display of dresses and robes worn by by-gone monarchs and by our present Royal family.

The function ended at about midnight.

Congress Banquet

(*Continued from page* 497.)

Dr. M. Barigozzi and Dr. R. Dupuis (Italy); Mr. L. Brasseur and Mr. A. Henks (Luxembourg); Prof. C. Gierdziejewski and Ing. J. Lutoslowski (Poland); Dr. H. A. Schwartz and Mr. W. R. Bean (U.S.A.); and Begs. Y. Granström (Sweden). Finally, he paid tribute to Dr. Vanzetti, of Italy.

Reply to the Guests

DR. GUIDO VANZETTI (President, International Committee of Foundry Technical Associations), made a clever speech in response, and was greeted with prolonged applause; his command of the English language belied the apologies he made for his alleged deficiencies. Although, he said, the delegates from overseas were guests, they really felt at home. Some of them would remain in this country for more than three weeks, and they always received here a warm and charming reception. The Congress, when held in England, always proceeded so smoothly that one felt that the organisation of a world congress was the easiest thing to do. But, to his dear English friends—Mr. Lake, Mr. Hepworth, Mr. Barrington Hooper, Mr. Delport, Tom (Mr. Makemson) and others—those who had experience of the work knew that it was a h—— of a job. He paid a tribute to them, and expressed thanks also on behalf of the ladies for all that had been done to make their stay in this country delightful and interesting.

Looking forward to the International Congress to be held in Italy next year, he expressed the hope that as many as possible would give his fellow countrymen and himself the opportunity to reciprocate the hospitality extended to them in this country. In the name of the real friendship existing between them, he drank to the health of all his hosts, to their prosperity, to their industry, and to their country.

The Health of the President

MR. J. HEPWORTH, J.P., M.P. (Past-President of the Institute), proposed the health of the President, Mr. Lake, at the same time congratulating the Institute and those responsible for his appointment, because the Institute could not have had a better man to grace that office.

(The toast was received with musical honours; and in the midst of the acclamation, an overseas delegate presented a bouquet to Mrs. Lake.)

The PRESIDENT, responding, thanked all who had contributed to the marked success of the Congress. In the first place he thanked the owners of works who, at considerable inconvenience, had thrown open their works to the delegates, and in the majority of cases had offered entertainment. He thanked also those who had contributed to the funds which had made the Congress possible, and all the members who had worked to that end. Though it was impossible to mention any number of them by name, he felt compelled to make one or two exceptions. Thus, he paid tribute to Mr. V. Delport (Secretary of the London Committee); to Mr. C. C. Booth (President of the London Branch); to Mr. Barrington Hooper, who had been responsible for most of the arrangements made for the entertainment of the delegates, and indeed, had been both the architect and the builder of the Congress; and to the wonderful organising ability of the General Secretary, Mr. Tom Makemson, and the splendid assistance of Mr. J. Bolton (Assistant Secretary) and their lady assistants. He thanked them all most heartily for their services to the Institute.

During the evening the President presented to Mrs. Hepworth, on behalf of the Past-Presidents of the Institute, a silver bowl as a memento of the past year, during which her husband had served the Institute as President.

The remainder of the evening was devoted to dancing.

Delegates and Officials photographed at the Opening of the Congress on Tuesday Morning.

Speeches at the Congress Banquet

A BRILLIANT FUNCTION IN LONDON LAST NIGHT

The organisers of the Congress had the opportunity last night, at the Congress Banquet held in the Dorchester Hotel, to entertain many distinguished guests, including a very large number of those who had ensured the success of the Congress by providing facilities so readily for the instruction and enjoyment of all who were attending.

Prior to the Banquet, the delegates and guests were received by the President and Mrs. Lake, and by Dr. Guido Vanzetti (President of the International Committee of Foundry Technical Associations) and Signora Vanzetti.

The President presided over the Banquet.

The Institute's principal guest was the Rt. Hon. Oliver Stanley, M.C., M.P. (President of the Board of Trade). Amongst other prominent guests were Sir William Larke, Mr. E. Bruce Ball, President of the Institution of Mechanical Engineers, and Mr. R. R. a-Ababrelton, Master of the Worshipful Company of Founders.

The Object of the Congress

The loyal toast having been honoured,

The RT. HON. OLIVER STANLEY, M.C., M.P. (President of the Board of Trade), proposing "The Foundry Industry and the Institute of British Foundrymen," first expressed his pleasure to be present and to join in the welcome to such a distinguished international gathering. In the world in which we lived, to-day, he said, there were perhaps too few occasions of welcoming as many guests from overseas as were welcomed on that occasion; and it was a great satisfaction to feel that so many people had come from so many countries to join in a friendly, if to the layman wholly unintelligible, discussion on matters of common interest. From whatever country we came, we must feel to-day that the world was a grim place in which to live. It was a world of tensions, of fears and of suspicion, a world fed only too often by the newspaper, speech and the broadcast. Some of us ordinary people must feel that, in all that daily diet which was practically forced upon our attention, a good deal too much attention was paid to the differences between nations, and only too little to the common grounds between them. (Applause.) There was one common ground upon which any decent men, with any responsibility in their own countries, must meet, and that was the desire to improve so far as they could the standard of life of the people, and to try to harness all the developments of science and the modern world to the amenities and the necessities of the common people of their lands.

In lighter vein, he said that although he could not claim any intimate connection with or knowledge of the foundry industry, ever since he was a boy, cast iron had had a peculiar connotation for him. He came of a racing family, and from his nursery days he had been accustomed to hear discussions dealing with "cast iron certainties!" Experience had taught him that it was quite unfair that the name of such a noble and durable metal should be associated with so variable a quantity as a horse. But to an outsider such as himself, one attraction of the foundry industry must be the fact that so large a portion of it, even in these days, was devoted to the needs of peace, and not to the needs of war. We lived in a world in which the whole, or nearly the whole, of the productive capacity of every country was devoted to the production of engines which, if they were ever used at all—and we all hoped they never would be so used—could have as their purpose only the destruction of life and of property. It was refreshing to think of an industry the greater part of whose products were used daily in the ordinary life of the ordinary man. When the ordinary man sat before his fire in the evening, that fire would be burning in an iron grate; his meals would be cooked on an iron stove; and, if occasionally he so far forgot himself to take a bath, he would use very often a cast iron bath.

The history of the iron founding industry in this country—and no doubt its history has been very much the same in other countries—made it a matter of peculiar interest and of a considerable amount of pride to the outside industrial

THE RT. HON. OLIVER STANLEY, M.C., M.P.
(President of the Board of Trade).

observer. It was a history unfortunately only too common with the passing of years, a history which must contain within itself a great many personal tragedies. It was an industry which for generations, and indeed, for centuries in this country was pre-eminent, until in the middle of the last century it had had an immense variety of uses and was, so far as this country was concerned, pre-eminent in the metallurgical world. But, just as the cotton industry, for example, was challenged by new textiles, and the railways and canals were challenged by new means of transport, so in the middle of the 19th century the iron industry was challenged by the growth of the steel industry, with new and cheaper methods. There would have been a great deal of excuse for people in those days, faced with a new and apparently overwhelming challenge, with the decay of the historic industry to which they belonged, with the decline of family businesses which for generations had enjoyed prosperity, if they had looked to the future with despondency and despair and with a spirit of surrender to the new forces.

Sphere of Research

It said a great deal for the industry and for the Institute that the challenge was not met in that way, but was met with courage, with enthusiasm and a determination to meet the new challenge with new methods. The success of the answer to that challenge had been due very largely to the Institute. To him the most interesting part of its work had been the emphasis it had placed upon and the assistance it had given to the work of research. In the first place, it had done a great deal in convincing individual units within the industry that the pooling of scientific information was not a loss to the individuals who gave it, but that it was the gain of the industry as a whole, and that the gain of the industry was the gain of every individual composing it. In the past, and in some industries even today, one found individual firms believing that they gained by keeping to themselves the scientific information which they might have acquired from the results of their own research. But how often had one seen that research reached its full value when it was pooled, that the value of the little bit one learned was doubled when placed alongside the little bit that somebody else had learned. In that respect the Institute and its propaganda had been a real lesson to the industries of this country.

The members however had also themselves set up a co-operative research organisation for the industry as a whole. One of the most difficult things in the world was to prove the £ s. d. value of research. Often he was asked by people in various industries whether he could show that it had improved their balance sheets. But the President of the Institute had given him one of the clearest instances he had ever seen in which the £ s. d. value of successful research to the industry which had financed it had been proved. The Research Association had discovered some new cupola method for cast iron in the foundry, and had shown already that the saving effected by that method was equal to at least three times the annual cost of the whole of the Research organisation. It was not often that one could obtain such direct proof of what he implicitly believed—that research, intelligently carried on by an industry, repaid its members a hundredfold eventually. The research organisation and the Institute had devoted their attention to improving the qualities of their product, to finding new qualities, to finding new uses for their products; and in so doing they were challenging successfully that competition which had hit them so hard formerly.

That co-operation within the industry, however, had not been confined to this country. It had encouraged a similar co-operation between the units of the world, between foreign countries and ourselves. So we had in the industry people of all countries placing at the service of others the experience and knowledge they had gained. In doing so, they were helping the industry as a whole, they were helping their own countries, and were helping the world.

Perhaps just as important as the exchange of scientific knowledge was the exchange of knowledge of human beings; and not the least important part of the Congress was that each got to know, not only the problems of an industry, but the problems of each other. We all got to know thereby something of the other person's difficulties, something of his point of view, of his fears, his suspicions and his hopes; and so the first step was taken towards understanding each other. When we understood each other we had taken the first and perhaps the longest step to peace.

An Industrial Metamorphosis

The PRESIDENT, responding, thanked Mr. Stanley most sincerely, on behalf of the Institute and the foundry industry, for the good wishes expressed and for the felicitous way in which the toast was proposed. He was conscious, he said, that in responding to the toast on behalf of the industry, he had undertaken a responsibility of considerable magnitude. The foundry industry was proud that it represented one of the oldest crafts in the world—the art of casting metals. It was proud of its traditions; but sometimes those very traditions, by reason of their age and of the tenacity with which they were held, might prove to be a handicap to progress. The industry was endeavouring to free itself from any such handicap.

The establishment of the Institute of British Foundrymen, 35 years ago, was due to a desire to apply to its ancient craft the results of modern scientific investigation and to govern it in accordance with modern conditions. The ideals which were set in those days had been steadily pursued ever since, and to-day the industry as a whole was up-to-date in its methods, in the application of science to its processes and in its equipment. The progress made in the industry during the last quarter of a century was remarkable, and that progress was continuing at an ever-increasing pace. Progress even during the last five years had been so extraordinary that it was almost impossible to keep pace with the many new departures which had come into being. He need only point to the developments in his own branch of the industry—steel foundry practice—to the very great developments in iron casting, and to the phenomenal growth of certain branches of non-ferrous foundry practice, particularly the founding of the light alloys.

The Institute of British Foundrymen stood for technical progress in the industry, and it was the technical or professional Institute of the industry. There were similar organisations in many other countries, which worked together very closely with the Institute. They all exchanged information annually, they held International Foundry Congresses, and they were the means of increasing the general level of all technical development; and, what was perhaps less easy to define, but even more important, they were the means of forming and maintaining close friendships between foundrymen of the different industrial countries of the world.

Ten years had elapsed since the International Foundry Congress was held in Great Britain, and at that time the President of the Congress was Mr. Wesley Lambert, whom they all welcomed on the present occasion (applause). The Congress was glad to be able to provide a platform for the interchange of ideas through the many technical Papers which were being presented; British foundrymen were glad to be able to show their overseas friends something of what was being done in the industry in this country, and they were delighted also to be able to reciprocate the hospitality and the friendly respects which many of them had enjoyed during their visits to the foundrymen of other countries.

Finally, the chairman again thanked Mr. Stanley for the interest he had shown in the Congress in many ways, for his presence at the Banquet, and for his very encouraging speech.

A Composite Toast

MR. BARRINGTON HOOPER, C.B.E. (President of the London Branch of the Institute) proposed, in his usual witty manner, the toast of "The Ladies, Guests and Overseas Visitors." For the sake of brevity, he said, three toasts had been combined into one; the era of amalgamation was entering even into after-dinner speeches. But most good things were combined or divided into three. For example, when called upon to make a speech, one usually made three—the one that was prepared, the one that was made and the one that one wished subsequently that one had made! Inasmuch as he was to address a gathering of scientists and engineers, he had composed the verse:—

"We read with pride of scientists
Who dam up river reaches;
But what we need is the scientist
To dam after-dinner speeches."

Addressing his remarks first to the ladies, he welcomed them heartily—their charm, their grace and their beautiful dresses. The ladies of today, he was told, like the prophets of old, had little honour in their own country. After entertaining the gathering for a while with apt stories, he assured the ladies, in the name of the Institute of British Foundrymen, and that wider gathering, the International Congress, that the men were delighted to welcome them.

Coming to his second chapter, he referred to the foundrymen as good, rough, hardy fellows, handy things to have about the house! Indeed, no home should be without one! There were men and foundrymen. The latter stood in a class by themselves, the superior class, men of iron, descendants of the Village Blacksmith type, whose motto was "Do right and fear no man: don't write, and fear no woman." Foundrymen, he said, were responsible for practically every modern device. Without them there would be no civilisation as we knew it today. Whether they should be praised or blamed for that responsibility he would not pretend to say! But it was a delight to extend to the many guests of the Institute a cordial hospitality. In a special welcome to the Rt. Hon. Oliver Stanley, he said the Congress was honoured by the fact that he had found time to attend, in the midst of his multifarious duties. He was a very fine English gentleman, and the son of one of England's most beloved citizens. (Applause). Possibly no Department of the Government was so vital to the industry as was the Board of Trade. The industrialists present could manufacture everything the engineer required; and through the Board of Trade they received assistance in marketing those products in adequate quantities.

Extending a most cordial welcome to the wonderful array of representatives of many countries, he recalled the many happy memories which British foundrymen retained of their visits abroad to the various Congresses and to the marvellous hospitality extended to them there. The warmth of their greeting in those other countries lived in their memories always.

Mr. Barrington Hooper made special mention of some of the distinguished visitors from abroad, though not all, because the list would have been very lengthy. As he said, his list was not comprehensive, and each of them was greeted with loud and prolonged applause. They were:—Mr. R. Deprez and Mr. J. Léonard (Belgium); Dr. Mont. Fr. Pisek and Ingenieur A. Benda (Czecho-Slovakia); Mr. J. Lobstein and Professor A. Portevin (France); Prof. E. Piwowarsky and Dr. H. Jungbluth (Germany); Ing. F. W. E. Spies and Dr. K. J. van Nieukerken (Holland); Mr. R. Erdös (Hungary);

(*Continued on page* 495.)

The Gathering at Last Night's Banquet in the Dorchester Hotel.

At Mr. and Mrs. Barrington Hooper's Congress Garden Party

Top Row.—Mr. J. H. Cooper; M. R. Théret; Mr. Barrington Hooper; Mr. V. C. Faulkner; Mr. W. B. Lake; M. J. Lobstein; Mr. C. C. Booth. **Second Row.**—Mr. and Mrs. W. Thomas; Mr. D. H. Wood; M. J. Rousseau; M. A. Brizon; Mr. E. Salinger; Mr. John Cameron; Mr. G. E. France. **Third Row.**—Mr. and Mrs. T. H. Gray and Mr. Gray, Junr.; Signor and Signora Mario Olivo; Herr and Frau H. Wachenfeld. *Bottom Row.*—Dr. J. W. Donaldson; Herr W. Rotmann and a lady friend; Mr. and Mrs. Alfred Augstein; Mrs. V. C. Faulkner; Mr. and Mrs. J. Ferdinand Kayser.

Mr. W. B. Lake's Presidential Address

We give below the full text of the Address which Mr. W. B. Lake, J.P., delivered at the opening meeting of the International Foundry Congress in London on Tuesday morning, immediately following his induction as President of the Institute of British Foundrymen. His theme was "The History of Steel Castings"

MR. HEPWORTH, LADIES AND GENTLEMEN,

I am deeply appreciative of the honour which you have accorded me in electing me your President at such an important juncture in the history of the Institute. I also regard my election as a recognition of the not unimportant part played by East Anglia in foundry developments. I hope that this International Congress will make a serious and lasting contribution to the cause of peace which foundrymen throughout the entire world so ardently desire.

A sincere welcome is being accorded to the visitors by distinguished representatives of the Government and by the civic authorities of this great city, and it is my first duty as President to add my own welcome and that of my colleagues in the Institute of British Foundrymen. My second duty is to address members upon a subject of my own choosing. My choice has been to compile a few notes on the subject of the history of steel castings, because steel castings have been one of the major interests of my career, and also because the subject shows how quickly the ironfoundry craftsmen developed the new steelmaking processes.

The History of Steel Castings

Although steel had been made in this country since 1609 mainly by the cementation process, it was not until about 1740 that the manufacture of steel castings became possible. Benjamin Huntsman, a watchmaker of Doncaster, desiring to improve the quality of his watch springs, invented the crucible furnace. Huntsman was of German parentage but a native of Lincolnshire. Prior to his time it was customary to use shear steel or cemented bar. As at no time during its manufacture had it ever been liquid, it contained slag, and this obviously created difficulties in the manufacture of such thin-sectioned articles as watch and clock springs. By melting cemented bar in the crucible the slag was removed by the simple process of decantation.

There can be no doubt that from the very early days of crucible steel making attempts were made to make castings, but progress in those days was slow owing to the poorness of communication. For instance, there was a lapse of about 70 years before the process crossed the Atlantic. The first successful manufacturers of crucible steel in the United States were the brothers Garrard, who established themselves in business at Cincinatti in 1831, the family originating from Laxfield, Suffolk.

The earliest record of the production of steel castings in Germany is the manufacture of steel rolls using cast-iron moulds by Friedrich Krupp of Essen, as early as 1832. However, the first individual to make steel castings in non-metallic moulds by a process involving the use of wooden patterns was Jakob Mayer of Bochum. In his earlier days, his enterprise was confined to the manufacture of steel ingots for forging, and by 1850 ingots weighing up to 3 tons were being made. But from the very beginning Jakob Mayer was interested in producing finished steel articles by casting metal directly into sand or loam moulds. Success was achieved in 1851, and in the following year he exhibited some cast-steel bells in Düsseldorf. Several peals of bells were delivered to a number of churches in 1853.

The first steel castings in the U.S.A. were made by the William Butcher Steel Works, now the well-known Midvale Company, in the late 60's.

During the next fifty years there was an ever-increasing production of crucible-steel castings despite the inventions of Bessemer and Siemens, but the general run of material made for the British market was medium carbon steel.

In 1904 the late Mr. F. H. Crittall, of Braintree, founder of the metal window industry, received information that steel castings could be produced more cheaply than malleable iron castings for metal window-fittings. He therefore suggested that I should accompany his son, Mr. (now Sir) Valentine Crittall, to the Continent to investigate the matter. Together we visited a number of foundries in Holland and Germany, and discovered that this particular crucible process had its origin in a works at Bonn, operated by Monkemoeller & Company. An inspection showed it to be working very successfully, and large quantities of sound castings possessing very good physical properties were being produced. Unfortunately, they were quite unsuitable for Mr. Crittall's purpose, as the cost was too high and the finish too rough.

Because this process yielded *mild* steel castings, which in 1900 were still not produced in either Sheffield or Scotland, my company entered into an agreement with the Monkemoeller concern by which they undertook to supply the necessary furnaces and working details. A new foundry was built and production was started in September, 1906. The process consisted of melting Swedish wrought-iron scrap in plumbago crucibles, and the great secret was the addition of a small quantity of aluminium to the molten metal. The product was marketed as "Millennium wrought iron castings." These castings were well received by the engineering industry, and a constantly increasing demand was experienced, so much so that, after about four years, a search was made for a cheaper method of production whilst retaining the same high quality, a matter to which I will refer later.

The Bessemer Process

The Bessemer process became a practical proposition in 1858, when Robert Mushet provided the means of killing the steel by spiegeleisen or ferro-manganese additions. It should be realised that this process takes for granted the production of liquid cast iron, and this affords me an opportunity to interject an interesting American sidelight. It was in the year 1643 that the first iron foundry was established in the United States. It was situated at the village of Hammersmith, now called Lynn, about 10 miles from Boston. The second foundry was established three years later in the same area at Braintree, whilst the third was at Raynham.

It is interesting to observe that America had an iron-foundry industry almost one hundred years before Huntsman invented the crucible process, and, judging by the names of the villages, men from East Anglia were largely responsible for its initiation.

Whilst there is still some doubt as to whether the theoretical concept of the pneumatic process of steelmaking was due to Sir Henry Bessemer or Mr. William Kelly, it is generally agreed that its success was due to Bessemer's mechanical genius and Mushet's application of metallurgy. Unquestionably, the original Bessemer process was used for the production of steel castings. For instance, the Pittsburgh Steel Castings Company, a crucible-steel concern, installed in 1881 a 5-ton Bessemer converter for the express purpose of making steel castings. This date is prior to the appearance of the various modified tuyere systems introduced between 1880 and 1900. Moreover, it is interesting to note that varying angles of blast were envisaged by Sir Henry Bessemer in 1862. He arranged for horizontal blowing to take place in a converter mounted on axes which admitted the placing of the tuyeres at any depth below the surface of the metal or above it if desired.

In 1884 the Robert type of converter was put into practical operation for the purpose of making steel castings at the Stenay Works, Meuse, in France. Robert's early experiments at Stenay on the Franco-Belgian frontier were so successful that in 1887 M. Cambier-Dupret installed two converters of this type in his works at Marcenelle. M. Cambier has sent me, through M. Paul Fassotte, his impression of those early days. Conditions were invariably bordering on the hectic, and nothing was known as to the quality of the iron necessary to produce steel suitable for castings. Experience showed, however, that hematite imported from Middlesbrough gave the most reliable results. It is difficult to imagine the troubles that those early steelmakers must have encountered without a laboratory, or a knowledge of either blowing times or pressures. What would be described to-day as a reasonably good heat of steel was then an exception, and credence can be given to the story—for it was confirmed in English practice too—that a casting free from blowholes was looked upon with suspicion. The market at that time was the colliery industry situated around Charleroi, where the new steel castings at least gave results superior to those yielded by grey iron castings for rolling stock. As the quality improved, so new markets were found and steel castings achieved a recognised position as a material of construction. The early specifications were quite modest, and 26 to 28 tons per sq. in. tensile, associated with 12 to 13 per cent. elongation, was considered adequate. The making of steel was surrounded by a great deal of mystery and the blowers considered themselves as being endowed by Providence with magic knowledge. It was generally accepted that the blowers could detect by smell whether a heat of steel would be satisfactory or otherwise!

At that time it was considered essential for the pig-iron to carry a minimum of 2 per cent. silicon for the production of good steel, whilst a brick lining lasting more than ten heats was deemed to be of outstanding merit. Carburisation was carried out with coke and a high carbon content was normal, so that an annealing process lasting from eight to ten days was considered necessary to ensure adequate malleability.

Shortly after the installation of the Robert converter, a M. Léonard became a sub-contractor in the Stenay works. He bought the liquid steel, provided his own labour, and sold the castings. This portion of the works, which made quantities of steel axle boxes for the Compagnie du Nord was, and still is to-day, known as the "Congo"—the implication warranted in the early days being that the men worked and looked like niggers.

About the year 1889, a French engineer, M. Alexandre Tropenas, whilst he was managing the works of Société Industrielle de Fonderie de

Bronze, induced his directorate to create a steel foundry based on the Robert steel-making process, but the tests, extending over six or eight months, were not deemed to be too reliable. However, he carried out a certain amount of experimental work that appeared to be very promising and when, in May, 1890, he met the late Mr. Alfred E. Wells, director in charge of Edgar Allen's steel foundry, discussion revealed that he was overcoming the very trouble that was being encountered in Sheffield. As a result, an arrangement was entered into for Mr. Tropenas to continue his experiments backed by the technical and financial resources of the English company. Success was finally achieved, and the system was extended to a good many foundries in the United Kingdom. Yet the true superiority of the Tropenas over the Robert is still a matter of speculation. A Robert converter was installed in the Atlas Works of John Brown & Company about 1890 and functioned with complete success. Moreover, about this time, there were fourteen Robert converters in the United States. Much of the later development of the Tropenas converter in the United Kingdom was due to the fact that it was manufactured and sold by Thwaites Brothers, of Bradford, whereas the Robert plant was not being "pushed."

It was not until 1897 that the Tropenas was installed in Germany, the first plant being ordered by the firm of C. Krautheim, of Chemnitz. The works manager of this concern, Herr Alexander Zenzes, a few years after set himself up in business as a manufacturer of small converter plants, having modified the design somewhat to suit German conditions, and in the course of time he installed a large number of these plants.

Stock Converter

There were no further inventions based on the original Bessemer system until 1906, when, at Darlington Forge, Mr. W. Stock started his experiments directed towards the melting by oil fuel and blowing in one and the same vessel. By 1908 he patented the process in all countries. The second installation was made at Thomas Summerson & Sons, of Darlington, and by 1913 the process had established itself not only in the United Kingdom, but also in France, Belgium and the United States.

The Siemens Process

It has been authoritatively stated that the Siemens regenerative gas-fired furnace was perfected prior to Bessemer's master patent of February, 1856, but though large-scale experiments were carried out both in England and in France, it was not until Dr. C. W. Siemens collaborated with Emile and Pierre Martin in 1864 that real success was achieved. The Martins contributed the steel-making process to the Siemens gas-fired furnace, and the process is known in English-speaking countries as the Siemens furnace and on the Continent as the Martin furnace. The process was introduced into America in 1868, at the works of the New Jersey Steel & Iron Company, of Trenton, New Jersey, but whether the plant was used for ingot-making or steel castings I have not been able to ascertain. In England, however, drawings were got out in 1862 by Dr. C. W. Siemens for Mr. Charles Atwood, the proprietor of Stanners Close Ironworks, Wolsingham, Co. Durham, for the manufacture of steel castings. This furnace was operated by Mr. William Shaw, founder of William Shaw & Company, Limited, of Middlesbrough, and it was here that the dredger buckets for the Suez Canal and some for the Panama Canal were made.

Though Krupps started to manufacture castings in 1863, they used no process other than the crucible until 1886, when they absorbed the Asthower works at Annen, this being the first concern to utilise the Siemens furnace for the manufacture of steel castings in Germany. Krupps certainly installed Siemens furnaces in 1871, and Bochum in 1873, and gradually other steel foundries used both the acid and basic open-hearth furnaces for making steel castings. Amongst the works employing the acid process was the Oeking works at Düsseldorf, the products of which became famous.

The Siemens furnace was introduced into the works of the Steel Company of Scotland in 1873, but it was not until 1880 that the process was used for making steel castings. The plant used initially was an 8-ton capacity furnace, for making general engineering castings. The capacity was increased from time to time until it attained two 40-ton furnaces.

Electric Furnaces

In the development of the electric furnace, Siemens certainly carried out some experiments and obtained patents. The Kjellin furnace was tried out in Sheffield about 1908 before the advent of the electrode furnaces. The Héroult, and the Stobie design of Electro-Metals furnace, were introduced into Sheffield in 1911, but these plants were not installed for the purpose of making steel castings, and historians credit my company in 1910 with the distinction of being the first foundry in the United Kingdom to install an electric furnace for the sole purpose of making steel castings. The crucible business having made good progress, there was a distinct incentive to search for a process capable of giving really mild easily-machinable castings at a lower cost and perhaps in larger quantity than the existing plant. Our friends, the Monkemoeller Company, of Berlin, were, in 1910, successfully making steel castings in the Stassano furnace, and they recommended me to make a similar installation. After visiting their works, I decided to study the potentialities of the Girod and Héroult furnaces installed in plants located in South-East France. I therefore visited these gentlemen, and on my return to England I decided to install a single-phase Héroult furnace. It was built by Campbell Gifford & Company and had a capacity of 2 tons. Current was applied through two round amorphous-carbon electrodes, and generated by an alternator driven by a Westinghouse gas engine. It produced good steel, but the refractory costs were very high owing to the electrodes being too near to the back wall, which involved rebuilding each week. The furnace worked regularly until 1916, when it was replaced by three larger furnaces of more modern design.

Unquestionably the United Kingdom lagged behind the Continent in the early development of the electric furnace. In 1905 Richard Lindenberg, of Remscheid, installed the first Héroult furnace, but this was for the manufacture of tool and special steels, the first installation for steel castings being made in 1908. About this time, A. Stotz, of Stuttgart, installed a Girod furnace.

In Italy, the pioneer work of the late Commendatore Vanzetti in both the field of electric furnaces and of steel castings is universally recognised. Whilst the British entered the field somewhat late, they made a serious contribution to design and wiring systems and some dozens of English-made furnaces were installed in France, Italy and Spain during and immediately after the war.

Although the U.S.A. were well to the fore in the development of the electric furnace, it was not until the same year that we started our electric furnace in Braintree that electric steel castings were made in America. Originally all the electric steel castings were made on basic hearths, but during the war a change-over was made to acid hearths, and to-day we find that, with the exception of manganese steel, 90 per cent. of America's electric steel castings are made on acid hearths.

The first electric furnace in Switzerland was of the Héroult type. It was put into service in October, 1907, at the works of George Fischer of Schaffhausen—a firm now famous throughout the world. The founder, Johann Conrad Fischer, was a constant visitor to this country between the years 1790 and 1840, meeting most of the celebrities of the engineering world, including James Watt.

The first electric furnace was installed in Spain during 1917, at Bilbao, by my friend Mr. V. C. Faulkner, but it was not regularly used for steel castings manufacture.

High-Frequency Furnaces

At the present time the high-frequency furnace is used chiefly for the production of special tool steels. But in some instances it is used in the production of steel castings. In October, 1928, my company installed the first high-frequency furnace for the production of steel castings. It was employed in making magnetic letters, which are so small that in some cases as many as a score are required to weigh 1 oz.

Pulverised Fuel-Fired Rotary Furnaces

This process as adapted for steel making has scarcely emerged from the experimental stage. In 1930 a 5-ton Sesci type of pulverised fuel-fired rotary furnace was installed at Neufmanil in the French Ardennes. An experimental cast of steel was made and no insurmountable difficulties were encountered, and even though the product was somewhat wild, some of it was cast in moulds prepared to receive malleable iron. M. Georges Fosseprez, managing director of the Mons Foundry Company, was present on this occasion, and thereupon decided to install two small furnaces for making steel castings. Trouble was experienced initially in the direction of carbon control, but it was completely overcome by installing improved fuel-grinding machinery. About the same time as the Mons plant was started up, Mr. W. Scott, of Sir W. G. Armstrong Whitworth & Company, also started making steel castings in a Sesci furnace, but the plant was not used exclusively for this purpose. The first plant installed in Great Britain for the sole purpose of making steel castings was in the Crewe works of the London Midland & Scottish Railway Company, and it was officially put into commission in September, 1935.

The first steel castings were made in the Brackelsberg furnace in September, 1932, at Bofors, but systematic production can only be counted upon from June, 1933.

No address upon any phase of the history of steel castings can be complete without paying tribute to Sir Robert Hadfield's invention of manganese steel in 1888. For a long time this constituted the sole special steel made in the foundry, and gave to it an advertisement such as has never been equalled in any other branch of the industry.

The three major inventions from which the steel foundry has benefited were made by British subjects of foreign origin. Huntsman's parents were German, Bessemer's were French refugees, and the Siemens brothers were naturalised British subjects of German origin.

Finally, it is significant that only in very recent years has the steel foundry commanded the serious attention of research. But at the present time there are two research committees engaged on this important work, namely, the Steel Castings Research Committee of the Iron and Steel Institute and the Steel Castings Section of the Technical Committee of the Institute of British Foundrymen.

Acknowledgments

I wish to acknowledge with gratitude the help given me by the following gentlemen in the preparation of this address:—Mr. J. H. Cooper, M. Paul Fassotte, Mr. V. C. Faulkner, Dr. Th. Geilenkirchen, Mr. F. Nolan (Bofors), Mr. Thos. Nairn, Mr. H. A. Shaw, Mr. Chas. W. Townsend, Mr. N. F. Hindle, and the management of the George Fischer Company.

Institute of British Foundrymen's Annual General Meeting

AWARDS OF MEDALS AND ELECTION OF OFFICERS

On Monday, June 12—the day preceding the official opening of the International Foundry Congress—the Institute held its 36th Annual General Meeting, at the Dorchester Hotel. Mr. J. Hepworth, J.P., M.P. (the retiring President) presided.

The minutes of the preceding Annual General Meeting, held in June, 1938, at Bradford, were taken as read, and the minutes of the adjourned Annual General Meeting, held in Manchester on October 15, 1938, to confirm the alterations to the Bye-laws that were approved in June, were read. They were confirmed and signed.

Arising out of the minutes of the October meeting, the SECRETARY (Mr. T. Makemson) said that active steps were being taken to secure a supplementary Charter; it was hoped to obtain it shortly, and that the new Bye-laws would come into force on January 1, 1940.

Council's Report and Accounts

On the motion of the PRESIDENT, seconded by MR. C. BIGG (Past-President), the Annual Report of the Council for the year 1938-39 was unanimously adopted, without discussion.

The Report is reproduced on pages 502-4 of this issue.

MR. S. H. RUSSELL (Past-President and Honorary Treasurer), proposing the adoption of the balance sheet and accounts for the year ended December 31, 1938, commented that the income had exceeded expenditure by the comparatively small amount of £122; if the South African Branch had not been in existence, that surplus would have disappeared entirely.

The motion for the adoption of the balance sheet and accounts was seconded by MR. V. C. FAULKNER (Past-President) and carried.

Report of Technical Committee

MR. J. W. GARDOM (Convener of the Institute's Technical Committee, proposed the adoption of the Committee's Report for the past session, and said that the work of the Committee since its inception in 1931 would be reviewed in a Paper before the Congress. He took the opportunity to thank the members of the Technical Committee for their help.

The motion was seconded by MR. C. H. KAIN, and the Report (see page 505) was adopted.

Awards

It was reported that medals and diplomas had been awarded as follows:—

Oliver Stubbs Gold Medal, 1939, to Mr. J. G. Pearce (Director and Secretary, British Cast Iron Research Association).

Meritorious Services Medal (which had not been awarded for some years) was awarded for 1939 to Mr. J. E. Cooke, who until recently was Secretary of the Lancashire Branch and is still carrying on a great deal of work on behalf of that Branch.

The E. J. Fox Gold Medal.—The Council have accepted the recommendation of the two assessors (Sir William Larke and Sir Harold C. Carpenter) and have awarded the Medal to Dr. Harry A. Schwartz, of Cleveland, Ohio, U.S.A.

Diplomas were awarded to the following:—Mr. W. W. Braidwood, for a Paper on "Melting Practice in a Large Engineering Iron Foundry," presented to the Scottish Branch; Mr. S. Carter and Mr. A. W. Walker, for their Paper on "Moulding Sand, with special reference to Blind Scabs," read before the West Riding of Yorkshire Branch; Mr. R. D. Lawrie, for a Paper on "Some Examples of Loam Moulding"; Mr. J. Dearden, for a Paper on "Moisture in Moulding Sand," and Mr. Walter West and Mr. C. C. Hodgson, for a Paper on "Porosity in Cast Iron."

Election of Officers

The following officers were elected for 1939-40:—

President—Mr. W. B. Lake, J.P. (director, Lake & Elliott, Limited, Braintree).

Senior Vice-President—Major R. Miles, M.Eng. (Director, Head, Wrightson & Company, Limited, Thornaby-on-Tees).

Junior Vice-President—Mr. D. H. Wood (Constructional Engineering Company, Limited, Birmingham).

The election of Mr. Lake was proposed by the retiring PRESIDENT, who expressed the confidence which Mr. Lake enjoyed among the whole membership. MR. C. C. BOOTH, J.P. (President of the London Branch), who seconded, spoke from practical experience of Mr. Lake's valuable work for the Institute for many years, and the encouragement he had given to members of his staff to assist the organisation. The members of his family also had given him great support.

In his response, MR. LAKE confessed that he had been a little nervous about accepting the office; his health had not been too good recently. Yet he had so many friends in the Institute and had received so many offers of help that he was able to accept the office with a good heart. He thanked the members very sincerely for the honour.

The election of Major Miles was proposed by MR. LAKE, who commended his admirable work as Junior Vice-President during the past year, and said that the more the members saw of him, the more they liked him. The resolution was seconded by MR. F. J. COOK (Past-President). MAJOR MILES briefly responded.

Proposing the election of Mr. Wood to the Junior Vice-Presidency, MR. F. J. COOK said it was unnecessary, in a company of foundrymen, to extol his virtues. He was well known as a hard worker for the Institute for very many years, and would have the support of the whole of the Birmingham Branch particularly when, in due course, he filled the Presidential Chair. MR. J. CAMERON (a Past-President), as an old personal friend of Mr. Wood, claimed the pleasure of seconding. He referred to Mr. Wood as one of his most valued friends, and commended his great work as President of the Birmingham Branch. MR. WOOD expressed his appreciation of his election, first as an honour to the Birmingham Branch, and secondly, as an honour to himself.

Votes of Thanks

MR. W. B. LAKE, proposing a hearty vote of thanks to Mr. Hepworth for his services as President during the past year, recalled the wonderful success of the Bradford Conference last year, and the great work Mr. Hepworth had done to ensure its success. Throughout the year he had rendered great service, in spite of the calls which his Parliamentary and other duties made upon his time, and the members were deeply indebted to him.

No seconder was needed for so popular a proposal, and the vote of thanks was accorded with enthusiasm.

MR. HEPWORTH, in his response, assured the members that he was honoured to have served as President; and he paid tribute to the officers and members of the West Riding Branch for their support, and particularly for the noble manner in which they had worked to ensure the success of the Bradford conference. He was all the better for having made the acquaintance of so many members, and hoped that the acquaintance would ripen into friendship as the years passed.

PROFESSOR T. TURNER, proposing a hearty vote of thanks to the officers and Council for their services during the past year, said that the Annual Report indicated the work that had been done and the progress which the Institute had made during the past successful year. An institute, he said, did not make progress if left to itself; if it were allowed to drift, it would drift downwards. The Institute's rising importance and increasing work was a great testimony to the work of its officers.

The resolution was seconded by MR. E. BROWN, and carried with acclamation.

Auditors

On the motion of MR. V. STOBIE (Past-President), seconded by MR. J. W. GARDOM, Messrs. J. & A. W. Sully & Company (chartered accountants) were re-appointed auditors for the ensuing year.

Election of Members of Council

The following five nominees for election to the five vacancies on the Council were declared elected for two years:—Mr. V. Delport; Mr. E. Longden; Mr. H. J. Roe, Mr. P. A. Russell, and Mr. A. W. Walker.

The Annual General Meeting closed.

Dr. H. A. SCHWARTZ

E. J. FOX GOLD MEDALLIST

Mr. Schwartz was born in Oldham County, Kentucky, and educated in the public schools of Louisville and the Rose Polytechnic Institute. He graduated with the degree of B.S. in 1901, and M.S. in 1903, when he joined the National Malleable & Steel Castings Company of Cleveland, Ohio. After a period as superintendent he was made manager of research in 1920—a position he still holds. His old Institute recognised the eminence he had achieved in the metallurgical field by bestowing on him the honorary degree of Sc.D. in 1933. In 1936 he was honoured by the Case School of Applied Science by receiving the honorary degree of D.Eng. He now acts as professorial lecturer in metallurgy at the Case School. He is either author or co-author of some 75 technical Papers, including three international Exchange Papers. His most recent Paper was "The Conversion of Solid Cementite into Iron and Graphite," presented to the Iron and Steel Institute. He is also well known as the author of "American Malleable Cast Iron," published in 1922.

Annual Report of the Institute of British Foundrymen

Presented at the Institute's Thirty-Sixth Annual General Meeting held in London on Monday

This Report covers the period May 1, 1938, to April 30, 1939, and the accounts are for the year ended December 31, 1938.

Another increase in the membership of the Institute is shown in Tables I and II, whilst the balance sheet and statement of accounts show that the finances of the Institute have been maintained in a sound condition, although during the past year considerably increased expenditure has been borne. The Council is also pleased to assure members that all phases of the Institute's work have made progress, and that the industry continues to recognise the value of this work.

Deaths

The Council regrets to report the deaths of seventeen members. Particular mention is made of the following who were widely known throughout the industry, and whose work on behalf of the Institute has undoubtedly assisted in the past to bring about the happy position in which the Institute now finds itself.

Mr. S. A. Gimson, J.P., East Midlands Branch, was one of the oldest members of the Institute, which he joined in 1906, and of which he was President from 1913 to 1915.

Mr. W. J. Molineux contributed several valuable Papers, for one of which he was awarded a diploma. At the time of his death he had been nominated as President of the Birmingham Branch, and had previously been a Vice-President of the Newcastle Branch.

Mr. E. V. Ronceray joined the Institute in 1909, and was elected an Honorary Member in 1922. He was a Past-President of the Association Technique de Fonderie. He had been decorated by the French and by foreign Governments, and had received honours from numerous technical institutions.

Mr. D. H. Wilkinson, a Past-President and former secretary of the Birmingham Branch, was also a diploma holder.

Mr. F. C. Edwards, a prominent member of the Birmingham Branch, will long be remembered for the valuable Papers on patternmaking which he presented to many Branches of the Institute.

Mr. J. R. Hyde, a Past-President of the Sheffield Branch, died in June, 1938, after twenty-seven years of membership of the Institute. For many years he was a member of the Council and was the first Convener of the Steel Castings Sub-Committee. He was the author of several Papers, for one of which he was awarded a diploma.

Mr. D. M. S. Parker, during his short membership of the London Branch of the Institute, became widely known, particularly to members of that Branch.

Mr. Kenneth Hill was also a comparatively new member of the London Branch, and was widely known, particularly to those members associated with the vitreous enamelling industry.

Mr. J. B. Corrie was a member of the London Branch who was well known throughout this country and on the Continent.

Mr. C. H. Smith, who was killed in a street accident last November, was a well-known member of the East Midlands Branch.

Mr. R. Potter was elected to membership in 1932, and was a valued member of the Scottish Branch.

MAJOR R. MILES
(*Senior Vice-President of the Institute*).

Honours Conferred upon Members

Amongst those members who received honours during the twelve months covered by this report are the following:—

The Rt. Hon. Lord Weir of Eastwood, P.C., G.C.B., was created a Viscount at the time of His Majesty's birthday last June.

Professor Sir Harold Carpenter, M.A., Ph.D., F.R.S., A.R.S.M., received the platinum medal of the Institute of Metals for the outstanding services which he has rendered to the development of non-ferrous metallurgy. Sir Harold has also been elected an Honorary Member of the American Institute of Mining and Metallurgical Engineers.

Professor-Emeritus T. Turner, M.Sc., F.I.C., F.C.S., A.R.S.M., was elected a Fellow of the Imperial College of Science and Technology.

Dr. T. Swinden was awarded the M. C. James Gold Medal by the Council of the North-East Coast Institution of Engineers and Shipbuilders.

Mr. J. E. Hurst, Past-President, was elected to the Presidency of the International Committee on Testing Cast Iron, and in July next will receive the honorary degree of Doctor of Metallurgy from the University of Sheffield.

Mr. V. Delport was awarded the Gold Medal of the Association Technique de Fonderie de France.

Mr. W. T. Griffiths, M.Sc., was awarded the degree of Doctor of Science by the University of Wales.

Mr. G. E. France was elected President of the Foundry Trades' Equipment and Supplies Association.

Mr. Frank S. Russell was elected President of the Refractories Association of Great Britain in May, 1938.

Mr. W. T. Laverton was elected President of the Stoke-on-Trent Association of Engineers.

Mr. R. C. Tucker, M.A., was elected President of the Sheffield Metallurgical Association.

TABLE I.—*Changes of Membership*, 1938–39.

	Subscribing firms.	Members.	Associate Members.	Associates.	Associate students.	Total.
At April 30, 1938	73	926	1,053	137	31	2,220
Additions and transfers from other grades	2	85	116	17	4	224
	75	1,011	1,169	154	35	2,444
Losses and transfers to other grades ..	1	37	75	21	3	137
At April 30, 1939	74	974	1,094	133	32	2,307

TABLE II.—*Analysis of Membership, April* 30, 1939.

Branch.	Subscribing firms.	Members.	Associate members.	Associates.	Associates (students).	Total.
Birmingham ..	8 (8)	157 (151)	157 (156)	15 (17)	7 (7)	344 (339)
East Midlands ..	4 (4)	67 (64)	102 (87)	5 (4)	2 (1)	180 (160)
Lancashire	14 (14)	127 (115)	198 (210)	25 (32)	— —	364 (371)
London	10 (9)	203 (187)	125 (117)	5 (6)	— —	343 (319)
Middlesbrough ..	1 (1)	27 (23)	44 (34)	8 (9)	7 (7)	87 (74)
Newcastle	7 (7)	34 (34)	30 (29)	56 (49)	11 (10)	138 (129)
Scottish	7 (6)	99 (104)	185 (191)	6 (7)	2 (2)	299 (310)
Sheffield	6 (7)	97 (96)	69 (67)	2 (2)	1 (1)	175 (173)
South African ..	10 (10)	41 (36)	27 (17)	7 (7)	— —	85 (70)
Wales & Mon. ..	2 (2)	44 (44)	51 (50)	— —	2 (3)	99 (99)
W.R. of Yorks. ..	5 (5)	55 (51)	89 (79)	3 (4)	— —	152 (139)
Unattached ..	— —	23 (21)	17 (16)	1 —	— —	41 (37)
	74 (73)	974 (926)	1,094 (1,053)	133 (137)	32 (31)	2,307 (2,220)

Sir Robert A. Hadfield, Bart., F.R.S., was honoured by the American Institute of Mining and Metallurgical Engineers in recognition of his fifty years' membership. The honour carried with it a diploma and a gold pin, insignia of the Legion of Honour of the Institute.

Finances

The increase in membership, and the increasingly active part which the Institute is taking in affairs connected with the industry, have both contributed directly and indirectly to the additional expenditure which has been incurred during the past year. Nevertheless, the excess

of income over expenditure at December 31, 1938, amounted to the sum of £122 11s. 10d.

Awards

E. J. Fox Gold Medal.—On the recommendation of the assessors, Sir William J. Larke and Professor Sir Harold Carpenter, the Council decided to award the E. J. Fox Gold Medal for 1938 to Mr. J. E. Hurst, "in recognition of his work on the metallurgy of cast iron and the application of the results of his research to the industry." The presentation of the medal was made at the Annual Conference in Bradford in June, 1938.

The Council has accepted the recommendation of the assessors to make the 1939 award to Dr. Harry A. Schwartz, of Cleveland, Ohio. It is expected that Dr. Schwartz will attend the International Foundry Congress, to be held in June, when the presentation will be made to him.

Oliver Stubbs Gold Medal.—At their meeting held in Bradford, on June 14, 1938, the Council decided to accept the recommendation of the Literary and Awards Committee to award the Oliver Stubbs Gold Medal for 1938 to Mr. S. E. Dawson, F.I.C., "in recognition of the many valuable Papers which he has presented to almost all the Branches of the Institute." The presentation of the medal was made at the Annual Conference on the following day.

Diplomas.—At the Bradford Conference last June it was announced that diplomas for 1938 had been awarded to the following gentlemen. The Branches to which they presented the Paper for which they were awarded a diploma are also shown:—

A. Tipper	...	Lancashire Branch
A. Phillips	...	Lancashire Branch
P. Fassotte	...	London Branch
B. MacDougall	...	Scottish Branch
J. Cameron, jun.	...	Scottish Branch

Buchanan Medals and Prizes.—The names of the recipients of the medals and prizes are given under the heading "Educational Work" which appears later in the Report. The Buchanan Medals and Prizes are awarded as the result of examinations organised by the City and Guilds of London Institute on Foundry Practice and Patternmaking.

Branch Activities

The system of presenting a Paper to more than one Branch has been continued during the past year in respect of several important Papers. Several Papers by new authors were also presented to the Branches, and the quality of such Papers was found to be of a very high order. Another pleasing feature of the programmes was the large number of Branches which included the Cast Iron Sub-Committee's report in their programmes. In all, nine Branches or Sections discussed this report, and in this way expressed their appreciation of the work which the Technical Committee and its Sub-Committees are undertaking.

The system of joint meetings between Branches has been extended this year. The Branches at Newcastle and Middlesbrough enjoyed joint works visits, while the Sheffield and London Branches held a two-days' joint meeting in London, when Papers were discussed and works visited. Among other new features included in the Branch Programmes were the Apprentice Patternmakers' Competition, organised by the Sheffield Branch, and the "Mock Trial" of "Castings *versus* Welded Structures," arranged by the London Branch.

The South African Branch continues to make steady progress, and the Council had an opportunity of welcoming to its January Meeting Mr. T. Nimmo Dewar, the first President of the Branch.

Kindred Institutions

The happy relations which have always existed between the Institute and other similar bodies have been continued during the year under review. Several joint meetings have been held between local Branches of this Institute and of the Institute of Metals and The Institute of Vitreous Enamellers.

The Council takes this opportunity of extending to the newly-formed Institute of Australian Foundrymen its best wishes for the success of this new venture, which will be officially represented at the forthcoming International Foundry Congress.

In order that there should be a closer working between the Institute and the British Cast Iron Research Association, a Liaison Committee was formed in 1937. Several meetings have been held during the last year and a useful measure of co-operation has been found possible.

The Council tenders its thanks to the Iron and Steel Institute for the opportunity which members had of participating in the discussion of the Third Report of the Steel Castings Research Committee, when it was presented to a Joint

MR. D. H. WOOD
(*Junior Vice-President of the Institute*).

Meeting of the two Institutes in the Autumn of last year.

The members of the Institute were also invited to attend a meeting of the Institution of Mechanical Engineers in December last, when the First Report of the Institution's Research Committee on High-Duty Cast Irons for General Engineering Purposes was presented by Mr. J. G. Pearce. Many members of the Institute availed themselves of this opportunity, and on their behalf the Council thanks the Institution and expresses the hope that such meetings may be continued in the future.

International Relations

Through the International Committee of Foundry Technical Associations, the Institute has been able to maintain its happy relations with foundry technical institutions overseas. A meeting of the Committee was held at the International Foundry Congress in Warsaw last September. The Institute was represented by Mr. J. Cameron, Senr., and the Secretary was also present as Secretary of the Committee. Over a dozen members of the Institute and their ladies were able to attend the Congress. The thanks of the Institute are extended to the Stowarzyszenie Techniczne Odlewnikow Polskich, who organised the Congress, and to Mr. K. Gierdziejewski, President of the Congress, for their hospitality.

In preparation for the next International Foundry Congress, to be held in London next June, contact has been made with thirty foundry and engineering technical associations in twenty countries. It is hoped that this Congress will afford a favourable opportunity for further strengthening the relations of the Institute with overseas foundry groups.

At a meeting of the International Committee for Testing Cast Iron held in Warsaw last September, Mr. J. E. Hurst, was elected Active President of the Committee. The Institute congratulates Mr. Hurst, and confidently hopes that under his Presidency the Committee will continue its useful rôle, and that through him, the Institute's participation in the Committee's work will be extended.

Mr. Hurst will attend the 43rd Annual Convention of the American Foundrymen's Association at Cincinnati and will extend to the American Foundrymen the good wishes of the Institute. He will also present the Institute's official Exchange Paper which has been prepared by Mr. F. Whitehouse.

The authors of other Papers presented on behalf of the Institute to overseas conferences were as follows:—

American Foundrymen's Association's Convention, 1938, Cleveland, Mr. W. J. Rees, M.Sc.

International Foundry Congress, 1938, Warsaw, Mr. B. B. Kent.

Association Technique de Fonderie, 1938, Lyons, Mr. T. R. Walker, M.A.

Papers were presented at the Bradford Conference on behalf of the American, French and German foundry associations. Official Exchange Papers from the following associations are expected to be presented at the forthcoming International Foundry Congress.

Nederlandsche Vereeniging van Gieterij-Technici.

Ceskoslovensky Odborny Spolek Slevarensky.

Stowarzyszenie Techniczne Odlewnikow Polskich.

Technischer Hauptausschuss für Giessereiwesen.

Magyar Ontodei Szakemberek Egyesulete.

Association Technique de Fonderie de Belgique.

Association Technique de Fonderie de France.

American Foundrymen's Association.

Federazione Nazionali Fascista degli Industriali Meccanici d'Italia.

Federazione Nazionali Fascista degli Industriali Metallurgici d'Italia.

Bye-Laws

Certain alterations to the Bye-Laws necessary to give effect to the re-organisation of the qualifications for membership were submitted to the Annual General Meeting at Bradford, on June 14, and passed at an adjourned General Meeting held in Manchester on October 15.

The Council is of the opinion that the alterations and additions which were made to the Bye-Laws will enable the Institute greatly to improve its status, and will benefit, both directly and indirectly, the individual member, who in return is called upon to pay an increased annual subscription. The new Bye-Laws will require intending members to show that they are fully qualified for the grade of membership to which they seek election, whereas at present such election depends solely upon the position which the intending member holds in industry. Membership will thus constitute a qualification. Additional advantages which the new Bye-Laws will facilitate were enumerated in a circular which was sent to all members prior to the adjourned Annual General Meeting.

Steps are being taken to ensure that the necessary supplementary Charter is obtained with the least possible delay, and it is expected that the new Bye-Laws will come into effect on January 1, 1940.

Publications

The Board of Development, on the Council's instructions, has reviewed the whole subject of the Institute's publications, and methods of publication, and has recommended to the Council

that certain alterations be made in the publication of the "Proceedings," in order to give better service to members. The Council has accepted these proposals which will be put into effect at an early date.

Educational Work

The Institute has continued to collaborate with the City and Guilds of London Institute in organising examinations in foundry practice and science and in patternmaking. The following are the results of the examinations which were held in April and May, 1938.

Patternmaking—Intermediate Grade.

Number of candidates.	Pass 1st class.	Pass 2nd class.	Percentage of passes.
32	11	10	65.6
Final Grade			
20	7	7	70.0
Foundry Practice and Science.			
80	28	29	71.25

Prizes were awarded to:—

PATTERNMAKING—*Intermediate Grade.*

William Charles Marshall, Derby Technical College. Bronze Medal of the City and Guilds of London Institute.

PATTERNMAKING—*Final Grade.*

Stephen Moorhouse, Huddersfield Technical College. City and Guilds of London Institute's Silver Medal, and Buchanan Book Prizes of the Institute of British Foundrymen.

Edward Kenneth Greenwell, Constantine Technical College, Middlesbrough, Buchanan Silver Medal of the Institute of British Foundrymen.

Tom Draper, Keighley Technical College, Buchanan Book Prizes of the Institute of British Foundrymen.

FOUNDRY PRACTICE AND SCIENCE.

Jesse Reginald Simpson, South-East London Technical Institute. City and Guilds of London Institute's Bronze Medal and Buchanan Book Prize of the Institute of British Foundrymen.

Alfred Ronald Oldershaw, Nottingham University College. Buchanan Silver Medal of the Institute of British Foundrymen.

William Alan Backhouse, Central Technical College, Birmingham. Buchanan Book Prize of the Institute of British Foundrymen.

National Certificates in Mechanical Engineering issued by the Board of Education and the Institution of Mechanical Engineers, are endorsed by the President of the Institute in respect of those candidates who have been successful in special foundry subjects. Twenty-one National Certificates have been so endorsed during the last year, making a total of 176 since the scheme was commenced.

The degree course in foundry metallurgy at the University of Sheffield has now been in operation for nearly four years, and the first students who have completed the course have now entered industry. The establishment of the course has been fully justified.

The British Foundry School has also nearly completed its fourth year. The careers, subsequent to leaving, of those students who have taken the course show that it has achieved the object for which it was intended.

The Worshipful Company of Founders has during the past year established two scholarships whereby selected graduates of Universities may receive facilities for advanced education either in research, or a period in works, or foreign experience. The Council has accepted an invitation from the Master, Wardens and Court of Assistants of the Worshipful Company to co-operate with them in the scheme.

Annual Conference, Bradford

A very successful Annual Conference was held in Bradford from June 14 to 17. On June 14 the Annual General Meeting was held, and was followed by a civic reception at the Municipal Art Gallery. The Wednesday and Thursday were devoted to technical sessions and works visits, whilst on Friday, June 17, an excursion through the Yorkshire Dales was enjoyed. There was a large attendance at the Congress, and several members and visitors from overseas were present.

Mr. W. B. Lake, J.P., and Major R. Miles, M.Eng., were elected Senior and Junior Vice-Presidents respectively.

The thanks of the Institute are extended to the Rt. Hon. the Lord Mayor of Bradford

MR. S. H. RUSSELL
(Honorary Treasurer of the Institute).

(Alderman Henry Hudson, J.P.), the Lady Mayoress, and to the Corporation of the City of Bradford for the valuable assistance which they so willingly gave both to the organisers of the Conference and to the delegates, and also for the civic reception which will long be remembered by all those who were able to participate. The Council extends its thanks to the firms whose works were visited; to the authors of Papers; to the subscribers to the Conference Fund; and to all those who assisted in making the Bradford Conference so successful. Particular mention should be made of the work done by the West Riding of Yorkshire Branch officials, notably Mr. A. S. Worcester, Branch-President; Mr. H. Forrest, Chairman of the Conference Committee; Mr. W. G. Thornton, Honorary Conference Treasurer; and Mr. S. W. Wise, Honorary Branch Secretary.

British Cast Iron Research Association

The year 1938-39 has been one of steady activity and progress. Research Reports issued to member firms are being circulated at a rate of over one report each month and the Bulletin is now issued six times a year. In June, 1939, the current five-year period for grant from the Department of Scientific and Industrial Research terminates and the Department has agreed to continue the same grant for the next five-year period, subject to the industrial subscriptions being increased by £1,000. The support of all eligible foundries is therefore earnestly desired by the Council.

In the event of a national emergency arising, arrangements have been made by the Department of Scientific and Industrial Research for the Association to continue work for the benefit of the industry, and members may therefore rely on the continuation of the services to which they have become accustomed. Co-operation is being exercised with a number of Government departments on defence matters.

National Service

The Institute has accepted the invitation of the Ministry of Labour to co-operate in the compilation of the National Register of persons with scientific, technical, professional and higher administrative qualifications. The Secretary of the Institute has accepted the invitation of the Ministry of Labour to serve on the Mechanical Engineering Sub-Committee of the Central Register Advisory Committee.

Council

During the year, four meetings of the Council and more than twenty meetings of special and standing Committees have been held in addition to those of the Technical Committee and its Sub-Commitees. These meetings have been held in Sheffield, Bradford, London, Manchester, Birmingham and Glasgow.

Ten members of the Council are elected by ballot for a period of two years, five retiring each year. The five who so retire at the Annual General Meeting to be held on June 12 are:—Prof. J. H. Andrew, Mr. V. Delport, Mr. E. Longden, Mr. P. A. Russell, and Mr. D. H. Wood. All these gentlemen are eligible for re-election for a further period of two years, and with the exception of Prof. Andrew, offer themselves for re-election.

The thanks of the Council are tendered to the Convener of the Technical Committee, Mr. J. W. Gardom, for his devoted work in the leadership of the various activities of this Committee.

The Council also takes this opportunity to express its thanks to the International Foundry Congress (1939) Committee which during the past year has worked so energetically in arranging the International Foundry Congress.

International Foundry Congress

His Majesty's Government has graciously granted recognition to the International Foundry Congress, to be held in London from June 11 to 17, and has invited delegates to attend a Reception on Tuesday, June 13. The Congress will be opened by the Rt. Hon. the Lord Mayor of London, Sir Frank Bowater, on Tuesday, June 13, when Mr. W. B. Lake, J.P., will be installed as President.

Professor W. L. Bragg, O.B.E., M.C., D.Sc., M.A., F.R.S., will present the Fourth Edward Williams Lecture entitled "The Atomic Pattern of Metals." Ample time has been allowed for works visits and technical sessions, and there will also be a joint meeting with the Iron and Steel Institute. The Annual Banquet will be held on June 14; a Reception will be given by Mr. and Mrs. W. B. Lake on June 15, and Mr. and Mrs. Barrington Hooper will entertain delegates to a garden party at their home on Sunday, June 11.

A tour of the principal foundry centres of Great Britain has been arranged from June 18 to 30, during which time twenty-six foundries have consented to receive delegates. Hospitality will be extended to a considerable extent by various Branches of the Institute.

J. HEPWORTH,
President.

T. MAKEMSON,
Secretary.

Seventh Annual Report of the Technical Committee

Presented at the Institute of British Foundrymen's Annual General Meeting on Monday

During the past year the Technical Committee has actively pursued its policy of studying various developments which have been made in the foundry industry and in collaborating with other scientific bodies engaged in similar investigational work.

A general report of the work which it has done since its inception in 1931 will be presented to the International Foundry Congress in June, and from this Paper it will be seen that the Committee's activities are mainly connected with standardisation. It is because of the increasing amount of work which the Committee is undertaking in this sphere that it was decided to recommend to the Council that the Institute should become a member of the British Standards Institution, where, through members of the Technical Committee, the Institute is already well represented. The Council accepted this recommendation, and it is expected that this new development will enable the Institute, and particularly the Committee, to extend its useful work.

Relationships with overseas foundry associations have been maintained mainly through the International Committee on Testing Cast Iron, of which Mr. J. E. Hurst was elected President last September. It is hoped that the Technical Committee will be able to participate more fully in the programme of work arranged by the International Committee.

In the report of the Sub-Committee on Cast Iron, particular mention is made of the Special Report No. 1 (" Properties of Grey Cast Iron "), which has been published during the past year. This method of publication marks a new step in the service which the Institute renders to its members, and it is hoped that during the coming year and in the future more of these special reports will be published.

An important development in the co-operation between scientific institutions was the establishment of the Joint Committee on Foundry Sands. The Institute is represented on this new Committee by members of the Sands Sub-Committee.

During the past year the Costing Sub-Committee completed the work which resulted from the discussion of its report (" Recommendations Concerning the Establishment of Costing in the Grey Iron Foundry "). The Sub-Committee has, therefore, terminated its activities for the time being.

The Inquiry Bureau arranged by the Institute under the auspices of the Technical Committee has continued to provide members of the Institute with a useful service, which has been greatly appreciated.

The Technical Committee expresses the thanks of the Institute to those members who have given their time to the furtherance of the work which the Committee and its Sub-Committees have executed. Thanks are also extended to those firms which have so kindly provided facilities for members of their staffs to attend meetings; to those firms who have carried out research work and tests on behalf of the Institute, and to those firms who have co-operated with the Committee in connection with the questionnaires which have been circulated to industry during the past year.

J. W. GARDOM,
Convener, Technical Committee.

Sub-Committee on Cast Iron

During the past year the Cast Iron Sub-Committee has continued to co-operate with the British Standards Institution in handling specifications directly or indirectly related to cast iron. In this connection assistance has been given in the preparation of a series of specifications dealing with precision tools for engineers, in which recommended compositions are included.

During the year the specification for cast iron gears has been issued; this includes grades of alloy iron with and without heat-treatment. The Sub-Committee actively participated in the preparation of this specification.

The principal work of the Committee during the year has been the preparation and publication of the Paper on the physical properties of cast iron, issued as Special Report No. 1. This Paper discusses all the work carried out by the Committee in connection with the preparation of the High-Duty Cast Iron Specification No. 786—1938, and in addition gives as far as possible information on the general physical characteristics of cast iron. It was presented before nine Branches of the Institute by members of the Sub-Committee, and was in each case given a full discussion. The discussions by the different Branches have been collected and classified and will be published together with the considered reply by the Sub-Committee.

Further consideration was given during the year to the possibility of issuing recommended methods of running and risering grey iron castings. As a result of a questionnaire to a number of foundries, however, it was found that it would be impossible to issue recommended methods in view of the very wide difference in practice as applied to the successful production of one and the same casting in different works. Similarly, it was agreed that the Sub-Committee was not in a position to make recommendations covering methods of preparing high-duty cast irons.

An investigation is now in hand to determine the relationship between the physical properties of cast irons as determined by normal methods and by tests conducted on small rings as developed in connection with piston rings. In order to correlate the results of tests carried out by these two methods it has been arranged to prepare standard test-bars and ring pots simultaneously from different grades of cast iron, and to carry out the necessary tests as a basis for comparison. The ultimate object of this work is to endeavour to find a suitable method of testing for the toughness of cast iron, and this will be studied from the point of view of such properties revealed by the tests as elasticity, energy required to break the test-pieces, impact resistance, etc.

P. A. RUSSELL, B.Sc.,
Convener.

Sub-Committee on Malleable Cast Iron

During the past year the Malleable Cast Iron Sub-Committee has been almost exclusively engaged on work in connection with the revision of the British Standard Specifications for Blackheart and Whiteheart Malleable Cast Iron. A questionnaire upon this subject was circulated to the industry and this resulted in a 60 per cent. return. After tabulation of the data, the Sub-Committee was pleased to find that its own views were generally supported by the industry. After consideration of the replies, the Sub-Committee formulated tentative recommendations which it was subsequently found were not in complete agreement with those of the Committee of the British Cast Iron Research Association also engaged on this work. After preliminary correspondence had taken place a joint meeting between the two committees was arranged. This proved very successful and enabled recommendations to be tabled which received the support of both Committees. There are now only two items upon which further data are required before the British Standards Institution is requested to convene a meeting of the IS/35/3 Committee. These investigations concern the desirability of using a round bar or a flat bar with half-round edges for the bend test, and the choice of gauge length for the 0.357 in. dia. bar for whiteheart malleable. The work will be undertaken jointly by the two Committees.

A. E. PEACE,
Convener.

Sub-Committee on Melting Furnaces

All sections of the report which the Sub-Committee has been preparing on Melting Furnaces for Grey Cast Iron are now complete, and the final draft has been approved. Publication will be effected as soon as possible, and the report will be made available to all members of the Institute as Special Report No. 2.

L. W. BOLTON,
Convener.

Sub-Committee on Non-Ferrous Castings

Further progress has been made during the year with the Sub-Committee's work on the standardisation of non-ferrous casting alloys. As reported last year, a memorandum was submitted to the British Standards Institution covering the Sub-Committee's recommendation for standard specifications for two leaded gunmetals. This memorandum has received the consideration of the relevant committee of the British Standards Institution, and a further meeting will shortly be held after which it may be expected that a draft specification will be prepared and issued for comment.

The Sub-Committee was asked for certain recommendations on the revision of British Standard Specification 383 for 88-10-2 gunmetal castings and has submitted its views to the British Standards Institution.

Work on the three leaded bronze bearing alloys has now been completed and a report entitled " Recommendations for Three Leaded Bronze Bearing Alloys " has been prepared and is being presented at the International Foundry Congress in London. It is intended, after allowing for full discussion of this report by members of the Institute, to submit a similar memorandum to the British Standards Institution with a request for new specifications along the lines recommended.

It has been decided to proceed with the preparation of a report on the deoxidation and degasification of non-ferrous alloys.

L. B. HUNT, PH.D.,
Convener.

Sub-Committee on Refractories

Practical tests on cupola ganisters have been made during the past year. It is hoped that these will provide the Sub-Committee with data on which it will be able to draw up a draft specification. The Sub-Committee is not yet in a position to make definite recommendations but hopes to complete this work in the near future.

W. J. REES, M.Sc.,
Convener.

(*Concluded on page 541.*)

Fourth Edward Williams Lecture

Atomic Patterns of Metals

By Professor W. L. BRAGG, F.R.S. (The Cavendish Laboratory, Cambridge)

Delivered to the International Foundry Congress in London on Tuesday morning

You are all familiar with the crystalline nature of metals. If a piece of metal is polished and etched with a suitable reagent, the crystals of which it is composed are revealed as a mosaic fitting together like the stones in crazy paving. The separate crystals stand out distinct from each other because the reagent etches the surface of each into minute parallel facets which reflect the light in a characteristic way. Further, this technique of polishing and etching has become extremely useful in the study of metals, because the mechanical properties of a metal are found to depend on the size and shape of the crystals of which it is composed. While in a pure metal the crystals are all of the same kind, though differently orientated, in the general case of an alloy, two or more types of crystal may be present, and changes in the shapes of the crystal blocks cause variations in mechanical properties which are so extreme that it is hard to believe one is dealing with essentially the same material.

One has merely to think of the range of properties exhibited by iron containing a little carbon to realise anew how remarkable this phenomenon is. The only constituents are nearly pure iron (ferrite), the carbide of iron (cementite), and in some cases graphite, yet depending on the way these crystals are interleaved with each other and on their relative amounts we get the whole gamut of properties of cast iron, wrought iron, mild steel, hard steel, and so forth, with many finer aspects of behaviour and character about which you know so very much more than I do. The heat-treatment and forging or cold-working which finally gives the metal the desired properties does this by moulding the crystals of the mosaic into certain shapes. By experience, the appearance of the etched specimen under the microscope has been correlated with its mechanical properties; hence the value of the microscope as a useful tool in the industrial laboratory.

X-Ray Analysis

My theme in this lecture is the new technique of X-ray analysis as applied to the structure of metals. The crystalline nature of metals implies that the atoms are arranged in patterns. By means of X-ray analysis, we can not only discover the pattern in any particular case, but can also get more detailed information about the size and shape of the regions of perfect pattern, the way in which atoms of more than one kind are incorporated into it in an alloy, internal strain, and so forth. The information yielded by X-rays can be summed up by saying that it is what we would obtain if we had a microscope so powerful that it enabled us to see the atoms in the metal. One may picture a specimen which has been polished and etched in the usual way. Ordinary microscopic examination shows the mosaic blocks, layers, needles, etc., which we have learnt to interpret as regards their influence on the properties of the metal. We now swing round a higher-powered objective on to the axis of the microscope (X-ray analysis), and as we move the specimen about beneath it we see all the atoms drawn up in the serried ranks of a crystal pattern. If it is an alloy of one metal with a small proportion of another, atoms here and there are different from the rest, and we can see how the structure embodies these foreign atoms, whether they are arranged at random, or regularly, or get into clusters or sheets. The interpretation of the X-ray results is not so straightforward and simple as my analogy would indicate, for it depends upon a rather profound and often difficult analysis of the diffraction of X-rays by the material, but in principle we have an X-ray microscope at our disposal.

It is clear that such an examination provides a wealth of information which we cannot afford to neglect, and that we must see how it can be used to improve technical methods. A new method such as this is developed first of all by scientists working in a University laboratory. They have little or no experience of the technical side, and when they describe the new knowledge they have obtained, their opposite numbers in industry are apt to say with perfect truth, "This

PROFESSOR W. L. BRAGG.

is all very interesting, but it does not help us to understand why a certain alloy is good and another bad, why one heat-treatment gives the desired result while another is disastrous; in fact, it seems to have little bearing on the wealth of knowledge which we have acquired by experiment and observation over many years." By degrees, however, the gap is bridged. Tentative experiments with the new X-ray methods show that the information about atomic structure they give can be correlated with desirable or undesirable properties, and a body of empirical knowledge is acquired. Further, in a way which is difficult to define but none the less important, a new method like X-ray analysis furnishes us with new ways of thinking. It helps to "explain" the properties of metals, and although the explanation may be at first a very dubious and lame one, yet any guiding idea is better than none. When trying new combinations of metals or treatments there are so many possible permutations and combinations that any clue which indicates likely lines of advance is better than mere trial and error methods.

Industrial Application of Science

X-ray analysis is just at this stage when its importance in industry is beginning to be recognised, and like others who have devoted themselves to its development, I am very keen that industry should take full advantage of its possibilities. As I see it, there are two ways in which as pure scientists we can further this end. In the first place, we should try to express the results of our researches in as clear and direct a way as possible, in order that the busy industrialist, who has no time to wade through the mass of detailed observations and analysis with which we must support our conclusions in scientific Papers, may appreciate what we have found out. I rank this as of the first importance, and think that as scientists we are often to blame for our neglect to do our duty in this respect. The trouble nowadays is not so much any lack of new knowledge, but that there is such a profusion of Papers that no one can keep properly abreast even of his own particular subject. As I believe Sir Josiah Stamp put it recently, knowledge is being mined in laboratories and buried in periodicals, just as gold is dug out of the earth with great labour and buried in the vaults of the banks. The present lecture is an attempt on my part to fulfil my duty to describe as simply as I can what we have found out and what we are trying to do.

In the second place, it is our duty in the Universities to train young men who are adepts at this particular kind of work and who can be taken over by industry. It is no good minimising the training which is required. One must not think that it is only a question of buying the necessary apparatus and asking any laboratory worker to employ it at odd times. An X-ray analyst needs as long and specialised a training as an organic chemist or metallurgist if he is to take advantage of all the tricks of the trade which we have learnt by bitter experience. To employ a man who has not had this advantage is to court disappointment. On the other hand, as I think we can claim that the experience of several big concerns in this country has shown, an X-ray analyst of the right kind, when let loose in an industrial laboratory, can attack problems from an entirely new angle and arrive at solutions which have previously been unattainable. I am personally extremely keen to see the new method used in the right way, and welcome the opportunity afforded by this lecture to further the good cause.

Interpretation of Phenomena

The analysis of crystal structures by X-rays is carried out by observing how the crystals scatter or diffract a beam of X-rays falling upon it. The regular serried ranks of atoms scatter wavelets as the X-ray waves pass over them, and these wavelets combine to build up diffracted waves in certain directions according to well-known optical principles. The art of X-ray analysis consists in deducing, from the distribution and strength of these diffracted beams, the nature of the atomic pattern which has produced them. It is a curious and rather specialised art, because one cannot proceed by any cut and dried method. It is more like solving a cross-word puzzle than applying a logical mathematical analysis. A series of guesses must be made, and when the right one is hit upon everything falls into place with such completeness that the correctness of the solution is obvious. A first object is the discovery of the crystal pattern, but in the case of metal structures this is often of a simple nature and is easy to recognise. Further re-

finements consist in noting how the atoms (if more than one kind is present) are distributed amongst the points of the pattern, how extended are the regiments of atoms which have a pattern with the same orientation, whether there are certain preferred directions of orientation, and so forth. These points, which will be dealt with more fully below, assume a very great importance in the study of metals and alloys, and demand a thorough knowledge of physical optics and long experience in interpretation.

The Powder Method

The most widely used method of studying the structure of a metal or alloy is known as the "powder method." The alloy is reduced to a state of fine powder by filing or grinding, and a speck of this powder (equivalent to the amount of metal in a pin's head) is attached to a fine hair or placed in a very thin glass tube. The powder is mounted at the centre of a cylindrical "camera" and a photographic film is placed around its rim. A slit system allows a beam of X-rays to fall upon the speck of powdered material, and the diffracted X-rays are registered by the film. This is a method of universal application, since it is always possible to obtain the alloy in a powdered form, and it is easy to quench or anneal the powder and so get it into any desired condition. Often, however, the very act of powdering destroys some characteristic of the metal in bulk which we wish to study. In such cases one resorts to the less convenient method of allowing the X-rays to fall upon the surface of an entire specimen, and recording the rays which are diffracted backwards upon a film or plate. In special cases it may be possible to pick out single crystals of the alloy, or such crystals may form in a thin wire, and this permits a more thorough analysis of the diffraction. Whatever the method, the principle is that of recording the diffracted beams and deducing the nature of the atomic pattern which gave rise to them.

Face-Centred Cubic Structure

The structures of most metals belong to one or other of two very simple types, which are those we would expect for a number of spheres of equal size packed together tightly. Both these structures have "cubic" symmetry. Imagine a set of cubes stacked together in every direction, and then suppose the cubes to be represented by rods along the edges, making a sort of scaffolding as if we were erecting the steel framework of a building intended to have cubical rooms. We are going to sweep away this scaffolding eventually, it is merely a scheme of reference to describe how the atoms are arranged. In the first type of structure, called "face-centred cubic," an atom is placed at every cube corner and at the centre of every cube face. This is actually one of the most efficient ways of packing balls of a given size together. It would obviously be inefficient to place them at the corners of the cubes alone, for then the balls would ride on top of each other and leave large gaps. By placing them at cube corners and cube centres the greatest possible proportion of the available space is taken up, each atom having twelve neighbours packed tightly round it. The second way is not quite so space-saving, but nearly so. The atoms are placed at the corners of the cubes and at their centres, the so-called "body-centred cubic" lattice.

Copper, nickel, aluminium and lead, amongst the common metals, crystallise with a face-centred cubic structure, whereas iron and chromium have the body-centred cubic structure. Although the causes which lead to a metal taking up the one structure or the other are as yet imperfectly understood, it is clear that in the case of iron the balance is easily tipped one way or the other. Pure iron is body-centred at room temperature, becomes face-centred at 900 deg. C., and changes back to body-centred at 1,400 deg. C., not far below its melting point. This vacillation, as is well known, is an essential feature in the metallurgy of iron. Zinc and tin are examples of metals which have more complex structures.

Binary and Complex Alloys

When we pass from the structures of pure metals to those which are formed when two or more metals are alloyed together, the story becomes much more complicated. I may draw examples from a programme of research which has now been going on in my laboratory for several years under the direction of Dr. Bradley, who has been responsible for many developments of the powder method of X-ray analysis. We have been taking the common metals, iron, nickel, cobalt, copper and chromium, and examining their alloys with each other and with aluminium. I have put it in this way because there is a closer kinship between the members of the first-named group than between any of them and aluminium. Their alloys with each other are either body-centred or face-centred cubic like the pure metals, or are a mixture of body-centred and face-centred crystals when more than one phase is present. If aluminium is alloyed with them and while its quantity is still small, the simple structure of these metals continues to assert itself. The aluminium falls into line with them, and we get a structure in which, for instance, all the atoms are at the corners and face centres of cubes, but some of them are aluminium and the rest the atoms of the other metals. For brevity, the face-centred structures may be called α, and the body-centred β, irrespective of the constituent metals. The Greek letters α, β, γ were used for different types of alloys before their atomic patterns were known, and it is now somewhat difficult to devise a consistent nomenclature. Body-centred iron is conventionally called α for instance, and the face-centred alloys of copper are also called α. In the present general treatment it appears justifiable to override the former conventions and correlate these letters with structure types, because we otherwise get into such hopeless confusion when we come to deal with alloys of three or more metals. We may summarise by saying that the alloys of iron, copper, nickel, cobalt and chromium with aluminium are α or β, or a mixture of α and β, as long as the proportion of aluminium is not high. The iron-aluminium alloys, for instance, are body-centred until the number of aluminium atoms exceeds that of iron atoms.

With increasing aluminium the structures become very complex. Some have been worked out, others still defy analysis. Many of them are rather like the β structure but with certain atoms left out in a symmetrical way and the others shunted up to close the holes thus left. Finally, after a desperate effort to crystallise with some fancy structure which can still accommodate the foreign aluminium atoms, the problem is given up as hopeless, and the next phase which appears is almost pure aluminium, the metal dissolving very little of those in the first group.

The study of these complex phases (each phase has a characteristic crystalline pattern) is of great interest because of its bearing on metallic chemistry, for we want to know the reasons for the formation of the many patterns. It is interesting to note, however, that practically all the alloys of technical importance are α or β alloys, the complex structures being so brittle that they are useless. I need not therefore inflict upon you any description of the latter. If we examine by X-rays almost any of the metals which are practically useful, we find the diffraction pattern characteristic of body-centred cubic or face-centred cubic structures. There are a few exceptions such as the light alloys of magnesium now coming to the fore, and alloys of base metals such as tin and antimony.

Structure and Mechanical Properties

If all that X-ray analysis could do were to discover that our useful metals and alloys have an α or β structure, you might well question whether it were performing much service. However, it goes much further than this. The important (and difficult) part of the analysis consists in tracking down curious and subtle modifications of the arrangement of atoms on the lattice points, which have a profound effect on the mechanical and other properties of the metal.

To take the question of mechanical strength first, upon what does it depend? To be strong is in many cases the primary duty of a metal, but as yet we have hardly any idea as to what determines the strength. A pure metal in which the atoms are arranged with complete regularity as a single crystal has a vanishingly small resistance to deformation. A thin rod of cadmium, for instance, which has been carefully grown as a single crystal, feels as soft as butter and can be pulled out between one's fingers, the sheets of atoms slithering over each other like a pack of cards. This behaviour of a metal is in sharp contrast to that of crystals of other kinds such as crystals of minerals. A piece of quartz is none the weaker because it is pure and perfectly crystallised. Its atoms are held together by bonds which have to be broken before deformation can take place. A metal can hardly be called a true solid, because its atoms can undergo an almost infinite relative movement without destruction of the coherence of the substance.

Imperfections in Structure and Strength of Metals

The strength of a metal appears to be based on imperfections of structure which can be introduced in two ways. If the perfect crystal is distorted by cold-working so that it is broken up into a mass of crystallites with different orientations, it becomes strong and resists deformation. Its strength is also increased if the regularity of its crystalline array is disturbed by the introduction of foreign atoms, by alloying it with another element. As an analogy, let us compare the atoms to a number of cars in a car park If the attendant of the park knows his business, the cars are all arranged in regular rows, in a crystalline arrangement in fact, and when the owners come to reclaim them they can easily be withdrawn. Relative movements of the cars are possible just because of the regularity of their arrangement However, if the owners are allowed to park their cars with no arrangement whatever, they become jammed in a "solid mass." The direction of easy movement of one car is athwart that of its neighbours, and it will take much time and patience before the mass can be broken up. Alternatively, difficulties would be experienced if we alloyed the cars with charabancs irregularly distributed through the mass. They are wider and longer than the cars, and spoil the regularity of arrangement, so that again the rows of cars cannot be moved past each other. The immovability of the cars is not due to any linking of one car to its neighbours, but to the confusion.

The study of metals has made it clear that their strength comes, not from bonds between neighbouring metal atoms, but from irregularities of structure. The sheets of atoms in the perfect metal slither over each other quite easily, but must do so in certain directions related to the crystalline structure. If the metal is broken up into crystallites with different directions of easy glide, the movement in one crystal is incompatible with that of its neighbours and the whole mass jams. If foreign atoms are present they set up centres of local disturbance and strain and block the avenues of easy glide like lorries in a narrow street.

Although it seems to be established that the strength of metals arises in this way, and that their combined ductility and toughness are due to the ease with which atoms can glide past their neighbours combined with the jamming effect of

the imperfections caused by the movement, yet the proper theoretical basis for calculations of strength is still lacking. We have no way of calculating the elastic limit in terms of the structure, no way of estimating the tensile strength in figures. This is one of the most fascinating problems in the realm of the properties of matter, and many people are attacking it, but there are at present almost as many tentative theories as researchers upon the subject.

Impure α or β Structures

I now wish to picture the state of affairs in a metal which has one of these simple α or β structures, but which is not pure. We will suppose that metal A has a certain amount of another metal B alloyed with it, and that the B atoms, which replace A atoms here and there, do not fit comfortably into the common pattern. I will again take an analogy, that of a number of soldiers drawn up on parade, and as we are to have two kinds of atoms we will suppose the A soldiers to be thin and the B soldiers stout. The men are told to fall in, and do so in the order in which they arrive at the parade ground, the succession of A and B soldiers in each rank being a random one. When they are ordered to "dress," so that the ranks may be in line and the men in the ranks behind covering those in front, the trouble begins. The parade is bound to be ragged, because the stout soldiers occupy more room than the thin ones. How can matters be straightened out?

I have taken this analogy because the various solutions I am going to proffer correspond to the arrangements which X-ray analysis reveals in alloy structures. A heroic solution would be to tell all the fat men to fall out and parade by themselves in another corner of the field, and then to close up the ranks of their thin comrades. Another solution, involving less drastic troop movements, would be to bunch the fat men at certain points, so that the eye of the reviewing general is less offended by the random alternation of the two types as he runs it along the line. Another solution would be to shuffle the B soldiers, while keeping each in his own rank, until the B soldiers in the rear ranks covered those in the front rank. This would have the advantage of keeping the files in correct alignment. Still another solution is possible when the ratio of B to A soldiers is a simple one, when for instance there are equal numbers of A and B soldiers or when one soldier in four is stout. In the first case the men would be told to reshuffle until there is a regular alternation stout-thin-stout-thin along each rank. This would have the advantage of realising an absolutely regular formation, though I am afraid the parade would have a certain comic aspect which would not be pleasing to the serious military mind.

Reshufflings of just this type take place in an alloy structure. One must remember that when the alloy solidifies from the melt, the atoms do not necessarily remain fixed in the positions they first take up in the crystalline structure. Very considerable movements of atoms may take place within the framework of the solid state. The well-known process of making an alloy homogeneous is an example. The first portions to solidify have a different composition from the last, yet if the alloy is held at a temperature which is high, yet well below the melting point, a diffusion of atoms takes place which renders the whole homogeneous. In performing such movements atoms must wander distances in the structure which are many thousand times greater than the distance between neighbours, and as this is done by a successive process of neighbours changing places, such changes must be taking place with the greatest of ease. The energy which is required to make neighbouring atoms interchange their positions is supplied by the heat. The atoms are in violent random movement, and once in a while it chances that this movement piles up so much at certain places that a reshuffle of atoms takes place, the more frequently the higher the temperature.

Application of the Analogy

The analogy between an alloy and the ranks of unequal soldiers may be clearer if I take some specific cases as examples. Let us take the case of a metal A which at a high temperature can hold a certain amount of a metal B in solution. For instance, above 500 deg. C. aluminium can hold over 5 per cent. of copper in solution, and at 750 deg. C. silver can hold 7 per cent. of copper in solution. This implies that at the elevated temperatures the heat movements are so violent that the copper atoms are being knocked about from one position to another on the aluminium lattice. Although their position on the lattice involves considerable strain, which would be relieved if they got together in clusters to form separate copper-rich crystals, the heat movements are continually breaking up such incipient clusters and distributing the copper atoms all through the lattice. As the alloy cools, the tendency for the copper atoms to concentrate and "come out of solution" asserts itself. The alloy breaks up into crystals of two types, one consisting of aluminium containing only a fractional percentage of copper, the other a copper-rich alloy which is roughly $CuAl_2$ in the one case, and nearly pure copper in the other.

The final result of cooling the alloy depends, however, on the rate of cooling, and is the result of a compromise between two effects of temperature. The lessening violence of the heat movements as the alloy cools makes it possible for the copper clusters to hold together, instead of being evaporated throughout the aluminium lattice. At the same time the shuffling of atoms becomes a more sluggish affair, for the concentration of sufficient heat energy at one point to enable two atoms to interchange their positions becomes an even rarer event. We get different types of structure according to the rate of cooling, and in fact can illustrate with these alloys three of the methods of making a parade more regular which I have outlined above.

If annealed for a sufficient time at a temperature somewhat above 300 deg. C., the copper atoms come out of solution and form separate copper-rich crystals. This is the solution of withdrawing the stout soldiers from the ranks and drawing them up in a separate formation at the other end of the parade ground. If the alloy is rapidly quenched, the copper atoms have insufficient time to move, and remain in their random positions. This involves a state of considerable strain, and since even at room temperature the atoms are occasionally able to change their positions, a process takes place which relieves the strain somewhat. Its nature has been recently investigated by Preston at the National Physical Laboratory, and may be compared to reshuffling the soldiers till the stout ones in successive ranks "cover" each other so as to restore the regularity of the files. Copper atoms change place with nearest neighbours till they are arranged in minute flakes or sheets, a few atomic distances apart. If the alloy is warmed to between 200 and 300 deg. C., a further change takes place. The atomic movements become more lively, the flakes are broken up, and the copper atoms segregate into minute local clusters or islands, which is like grouping the stout soldiers at certain points in the ranks so that the break in regularity is not so apparent. At a still higher temperature, the mass movements take place which lead to the formation of separate large crystals. This succession of events has been confirmed by some recent measurements by Sykes and Swindells on the heat evolution or absorption which takes place in the alloy.

The rearrangements of the atoms have a profound influence on the mechanical properties of the alloy, which is known as "age-hardening." The random arrangement of the copper atoms in the freshly quenched alloy gives a Brinell hardness of about 65, which increases to 100 when the copper-rich flakes are formed, falls when they dissolve, and increases to about 80 for the general type of precipitation. In a copper-beryllium alloy the hardness increases from 100 to nearly 400 by the segregation of the beryllium atoms. Although we cannot calculate the hardness or mechanical strength, it is an important first step to have discovered the atomic arrangements which give rise to it. The segregation of the foreign atoms on this minute scale destroys the uniformity of the structure and gives rise to rapidly varying local strains which apparently stop the yield of the material under stress.

Another example is afforded by such an alloy as β-brass, which is composed of almost equal numbers of atoms of copper and zinc. The common pattern of points occupied by the atoms is the β structure, body-centred cubic. At high temperatures the points of the pattern are occupied indiscriminately by copper and zinc atoms. At low temperatures they sort themselves out, all copper atoms going to cube corners and zinc atoms to cube centres. This is the solution of placing equal numbers of A and B soldiers in a regular A-B-A-B arrangement in order to achieve uniform ranks. The rearrangement has a profound influence on certain physical properties of the material such as energy content and electrical resistance. Tammann many years ago divined that this reshuffling took place, but it is only recently that it has been confirmed by X-rays. Though not of great technical importance, it is of considerable scientific interest, because it affords one of the few cases where theory has been applied to a metallurgical phenomenon with conspicuous success. It has been found possible (Borelius, Dehlinger, the author and E. J. Williams, and others) to account thermodynamically for the course of the change. It is, of course, the heat movements which keep the atoms shuffled up at the higher temperatures, while they can sort themselves out at lower temperatures in a kind of further crystallisation within a crystal.

The Case of Permanent Magnets

As a last example, I may take certain alloys which are used for permanent magnets. It was discovered by Mishina in Japan that certain alloys of iron, nickel and aluminium are capable of retaining a very large amount of magnetic energy. The approximate composition is Fe_2NiAl. At high temperatures the atoms are arranged in a random way on a body-centred lattice. If annealed at lower temperatures, the alloy breaks up into two phases, one being almost pure iron and the other approximately FeNiAl. In neither condition are its magnetic properties at all outstanding. If cooled at the right critical rate, however, the process of separation of the iron is arrested in an intermediate stage. The iron atoms come together to form iron-rich clusters, believed to be in the form of sheets or plates, but they remain on the same body-centred pattern as the other atoms. Since the iron pattern is smaller than that of FeNiAl by about 1½ per cent. in volume, the constriction required to make all the atoms fit on the same pattern sets up enormous local strains. These strains make it difficult to reverse the direction of magnetisation of the material, once it is magnetised in a given direction, and hence a sample of the alloy magnetised by a strong electric current retains an intense magnetisation when removed from the field. This explanation was put forward by Bradley in the course of an investigation for the Permanent Magnet Association. Alloys of iron, copper and nickel show a similar effect.

The structures described above are not structures of ideal equilibrium. A cold-worked metal which has been broken up into a mass of crystallites has a higher energy than a single perfect

(*Concluded on page* 541.)

A Selection of Congress Papers

Nearly forty technical Papers and Reports are being submitted at the International Congress, and during the technical sessions held on Tuesday and yesterday, sixteen were presented. Of these a selection is given in the pages which follow. They cover castings ranging from quite small ones made by the die-casting process up to very large components built into steelworks plant. The remaining Papers, and the discussions at all the technical sessions, will be published in subsequent issues of the Journal.

BONDING CLAYS AND THE PROPERTIES OF SYNTHETIC MOULDING SANDS

By G. H. PIPER,* B.Sc., Ph.D.

[*Presented on behalf of the British Cast Iron Research Association*]

The use of synthetic moulding sands has extended rapidly over the last five years, as such material shows advantages in many cases over natural moulding sands. The chief advantages may be summarised as:—(1) Greater control of strength and permeability, and consequently fewer casting defects (natural sands have frequently a high silt percentage and too low a permeability); (2) suitability for mechanised sand plants; and (3) economy in operation.

The properties of synthetic moulding sands vary considerably, as they depend both on the type and amount of clay present and also on the base sand. The object of the present research was to determine the suitability of various clays for preparing satisfactory moulding sands when used as bonding clays, both for silica sands and natural moulding sands. Present knowledge of moulding sands has not yet reached a point where all the physical properties necessary for satisfactory moulding can be measured and specified, though continual advances are being made as the result of research, both in Europe and the United States of America. The properties of the synthetic mouldings investigated included the green and dry strengths, permeabilities and refractoriness and the influence of the clay and moisture content. These tests were supplemented by actual casting tests in which the influence of successive castings on the moulding sands was observed.

The clays examined were:—

China Clays.—Two china clays, termed A and B respectively, obtained from the large china clay deposits at St. Austell, Cornwall, were used for the tests. These clays occur together with quartz, felspar and mica and are separated from these coarse impurities by sedimentation. They had been milled to pass a 200-mesh sieve.

Ball Clays.—These were from two sources:—(1) Ball clays A and B, obtained from the ball clay mines at Wareham, Dorset. These clays are weathered in the open, and the lumps supplied were ground to pass a 30-mesh sieve before use. These ball clays are regarded as sedimentary clays and are believed to have been formed like the china clays from granite and to have been subsequently transported by river or other action to their present position. (2) Ball clay C, from a Devon deposit. It had been milled to pass a 200-mesh sieve.

Fireclays.—(*a*) Stourbridge fireclays. Six samples were obtained from the Stourbridge fireclay mines. They differed widely according to the seam from which they were obtained, some being highly siliceous. The nature of these deposits has been described in various publications.[1 2] The samples, which had been previously weathered, were ground to pass a 30-mesh sieve. (*b*) Scottish fireclay, a material obtained from the Bonnybridge district. It existed as a grey powder, and 98 per cent. of this material as used in the tests passed a 30-mesh sieve.

Bentonite.—A good quality bentonite from Wyoming, U.S.A., was used.†

Colloidal Clay A.—A proprietary bonding clay of Irish origin. It was an earthen coloured powder of ball clay character.

Red Clay from a natural moulding sand. For comparison with the other clays the red ferruginous clay in a natural Bromsgrove moulding sand was separated by repeated sedimentation of the sand with water. The clay suspension containing particles less than 0.01 mm. diameter was allowed to settle after flocculation.

Nature of Basic Silica Sand

The synthetic sands were prepared under standardised conditions, the base silica sand being Frankley medium fine sand having the following mechanical analysis:—

Grade.	Per cent.
Clay	0.3
Fine silt	0.5
Coarse silt	0.5
Fine sand	37.6
Medium sand	60.4
Coarse sand	0.7
Gravel	—
	100.0

The sand was mixed with the dried clay, milled two minutes dry in an August Simpson laboratory mill, water added, and then milled ten minutes. Tests showed that green strength was developed in five minutes and milling longer than ten minutes produced little or no change.

The green compression strengths were measured by the B.C.I.R.A. method at ramming densities of 1.5, 1.6 and 1.65, the results at ramming density 1.6 being given in Table I and shown in Fig. 1.

It will be observed that each green strength: moisture curve shows a well-marked maximum, the left side of the maximum being the region where the sand grains are too dry to cohere well on ramming. Table II summarises the

TABLE I.—*Green Compression Strengths of Synthetic Sands.*

3 per Cent. Bentonite.								
Water, per cent.	1.46	1.50	2.05	2.24	2.72			
Green strength	5.81	5.87	5.69	5.44	5.0			
5 per Cent. Bentonite.								
Water, per cent.	1.92	2.06	2.60	3.24	3.98			
Green strength	11.4	13.8	8.3	7.25	5.7			
5 per Cent. Colloidal Clay A.								
Water, per cent.	1.02	1.32	1.38	1.54	1.80	1.94	2.80	
Green strength	3.0	5.19	5.70	5.50	5.44	5.0	3.50	
5 per Cent. Ball Clay A (Dorset).								
Water, per cent.	1.68	1.94	2.04	2.26	2.52	2.88		
Green strength	4.12	5.56	5.56	6.12	5.25	1.44		
5 per Cent. Fireclay No. 6.								
Water, per cent.	2.10	2.20	2.54	2.86	3.50			
Green strength	4.28	5.0	4.94	3.94	2.19			
5 per Cent. Scottish Fireclay.								
Water, per cent.	1.76	2.18	2.48	2.96				
Green strength	2.75	3.0	2.87	2.1				
5 per Cent. China Clay A.								
Water, per cent.	1.44	1.78	1.84	2.24	2.46			
Green strength	2.26	2.37	3.56	3.5	3.34			
5 per Cent. Red Clay (from Natural Moulding Sand).								
Water, per cent.	2.26	2.64	3.60	4.54				
Green strength	4.63	5.0	5.0	4.5				

† Supplied by courtesy of the Frederick Crane Chemical Company, Limited, Birmingham.

* Formerly on research staff of the British Cast Iron Research Association.

maximum green strengths attained and the corresponding moisture content.

It is clear that bentonite has a greater bonding power than the other clays examined. Synthetic sands containing 3 per cent. of bentonite, 5 per cent. of colloidal clay A or 5 per cent. of ball clay A have approximately the same maximum green strength. The china clays have low bonding power and likewise the Scottish fireclay and No. 1 and No. 2 Stourbridge fireclays. In-

Table II.—*Critical Moisture Content to Yield Maximum Green Strength.*

Clay.	Max. green strength.	Moisture.
		Per. cent
5 per cent. bentonite	13.81	2.06
3 „ bentonite	6.0	1.7
5 „ colloidal clay A ..	5.7	1.5
5 „ china clay A ..	3.6	2.05
5 „ china clay B ..	2.9	2.6
5 „ ball clay A (Dorset)	6.1	2.3
„ ball clay C	4.2	2.8
5 „ fireclay No. 6 ..	5.15	2.35
5 „ fireclay No. 3 ..	5.0	2.1
5 „ fireclay No. 4 ..	4.19	2.44
5 „ fireclay No. 7 ..	4.13	2.3
5 „ fireclay No. 1 ..	3.7	2.3
5 „ fireclay No. 2 ..	2.25	2.0
5 „ Scottish fireclay ..	3.0	2.18
5 „ red clay	5.0	3.1

creasing the percentage of china clay to 8 to 12 per cent. gives an adequate green strength, but the permeability of the moulding sand is greatly diminished, as the figures (A.F.A.) of Table III show.

Fig. 1 shows that the green strength : moisture percentage curve depends on the clay, the sand bonded with 3 per cent. of bentonite giving a curve with a more rounded peak than the others. Such a curve would appear advantageous in that the properties of the synthetic sand are less susceptible to changes in moisture con-

Table III.—*Showing the Influence of Increasing China Clay Additions.*

	Permeability test. Secs. per litre air.	Green strength. Lbs. per sq. in.	Moisture. Per cent.
4 per cent. china clay	14.5	2.4	2.2
8 per cent. china clay	16.5	4.7	3.0
12 per cent. china clay	21.2	10.6	2.9
12 per cent. china clay	21.7	7.9	3.4

tent, alterations in the latter being unavoidable in the foundry owing to rapid evaporation from warm moulding sand. The properties of the sand bonded with the red clay extracted from a natural Bromsgrove moulding sand are remarkable; the maximum is hardly appreciable, and occurs at a moisture content far higher than the true synthetic sands.

Green Strength and its Relation to the Clay

The green strength and bonding power depend very considerably on the type of clay, and, in view of the importance of this property in moulding, it was of interest to investigate the relationship of green strength with the properties of the clay, and thus to elucidate the factors responsible for green strength.

A moulding sand consists essentially of sand grains coated with a thin layer of moist clay, and it is clear that the rupture of rammed moulding sand involving the separation of the coated sand grains must involve either the rupture of the moist clay layer or rupture between sand grain and clay layer. Experiments were carried out with two convex surfaces of glass coated with moist clay which were pressed together to imitate the sand surfaces in a moulding sand, and it was found that considerable force was required to separate the two surfaces and that, when separation occurred, the rupture took place in the clay layer itself. It thus appeared reasonable to expect, from these elementary experiments, that the green strength of the moulding sand would be related directly to the tensile strength of the moist clay. Experimental work proved that this was in fact the case.

The tensile strength of moist clay has been investigated by several workers, notably Hind and Degg.[3] They worked under conditions in which a gradual elongation of the clay could take place under the applied forces, and the time factor was therefore involved. To eliminate the influence of this gradual elongation as far as possible, and to imitate the conditions existing in a moulding sand, the tensile strength was determined on the moist clay with a length small in comparison with the cross-section. The moist clay was pressed between two glass surfaces to give a cross-section of 1 sq. in. and a clearance between the plates of 0.074 in., and the force required to separate the plates measured. The tensile strength decreased as the moisture percentage increased.

In Table IV the tensile strengths of the moist clay are given at the moisture content corresponding to the maximum green strengths of the moulding sand. It is clear that the green strength of the moulding sand, *i.e.*, the bonding power of the clay, is directly related to the tensile strength of the moist clay.

Table IV.—*Tensile Strength of Moist Clays.*

	Bentonite.	Colloidal clay A.	Ball clay A.	China clay B.
Parts of water per 100 parts (dry) clay	56.6	30	46	52
Tensile strength in lbs. per sq. in.	9.5	6.4	5.1	2.2

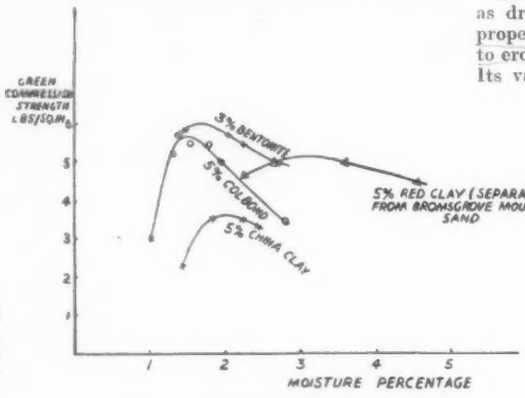


Fig. 1.—Green Compression Strength.

Dry Strength

This factor is important for green sand as well as dry sand moulding, as it is mainly on this property that the resistance of the mould surface to erosion by the stream of molten metal depends. Its value is especially important in the case of synthetic moulding sands which frequently have dry strengths considerably lower than those of natural moulding sands.

The dry strengths of the synthetic moulding sands at various temperatures of drying and initial moisture contents are given in Table V. The figures given, in lbs. per sq. in., are for a ramming density of 1.6.

The results, some of which are given in Fig. 2, show that the dry strength increases with moisture content and with the ramming density. The influence of drying temperature up to 250 deg.

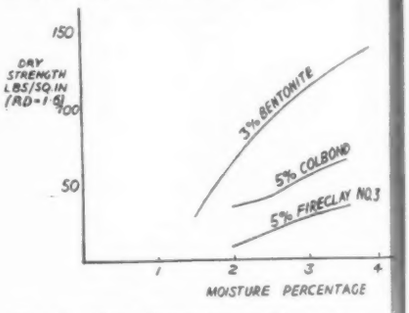


Fig. 2.—Dry Compression Strength.

Table V.—*Dry Strengths of Synthetic Moulding Sands.*

3 per Cent. Bentonite.					
Moisture, per cent.	1.50	1.90	2.40	3.76	
Drying temp., deg. C. 105	28	58	112	134	
Drying temp., deg. C. 150	30	56	91	90	
Drying temp., deg. C. 200	36	53	88	144	
Drying temp., deg. C. 250	30	63	87	134	
5 per Cent. Colloidal Clay A.					
Moisture, per cent.	1.84	2.14	2.80	3.46	
Drying temp., deg. C. 105	32	33	56	74	
Drying temp., deg. C. 150	34	33	74	82	
Drying temp., deg. C. 200	26	36	60	80	
Drying temp., deg. C. 250	36	35	50	62	
5 per Cent. Ball Clay A.					
Moisture, per cent.	2.26	2.76	3.20		
Drying temp., deg. C. 150	8	30	36		
5 per Cent. Fireclay No. 6.					
Moisture, per cent.	2.08	2.30	2.64	2.92	3.44
Drying temp., deg. C. 250	4	8	13	10	16
5 per Cent. Fireclay No. 3.					
Moisture, per cent.	2.18	2.38	2.70	3.32	
Drying temp., deg. C. 250	13	18	22	31	
5 per Cent. Scottish Fireclay.					
Moisture, per cent.	1.76	2.18	2.48	2.96	
Drying temp., deg. C. 105	3.4	5.9	8.4	14.0	
5 per Cent. China Clay A.					
Moisture, per cent.	2.16	2.74			
Drying temp., deg. C. 150	4.5	3.5			
5 per Cent. Red Clay (from Natural Moulding Sand).					
Moisture, per cent.	3.60	4.54			
Drying temp., deg. C. 250	40	40			

is not very marked. The bentonite bonded sand, using only 3 per cent. of bentonite, shows a higher dry strength than the other sands containing 5 per cent. of clay, and it is clear that for dry sand moulding its use is advantageous, as also for dry sand steel moulding sands, which are usually heavily bonded.

For green sand moulding the dry strength should be adequate to prevent erosion by the wash of molten metal. The greatest erosion occurs at the bottom of the ingate where the sand has to withstand the fall of metal from the ladle, and sand grains are liable to be carried into the mould and produce inclusions which are troublesome if the casting is to be enamelled or if a machined surface is required, as in the case of cylinder liners. It is difficult to fix a definite minimum dry strength since the erosion depends on other factors such as the type of casting, height from which the metal is poured, and the grain size of the sand, a coarse open sand probably resisting erosion less than a close packing fine sand. Further, if the effect of temperature rise is to diminish the dry strength, then the amount of erosion will depend on the dry strength at the higher temperature range where this weakness is shown.

Attempts to specify the dry compression strength necessary for green sand work have, however, been made. Dietert[4] gives figures found satisfactory for the following types of castings—flywheels, pipes, car wheels, cylinder blocks, the values ranging from 40 to 50 lbs. per sq. in. (A.F.A.). F. Hudson[4] gives green sand figures which are known to give good results (railway chairs and hydraulic valves), the dry compression strengths ranging from 40 to 60 lbs. per sq. in. (A.F.A.). Additions of sulphite lye were recommended when the dry strength fell too low.

TABLE VI.—*Dry Strengths at Normal Moisture Contents.*

	Moisture. Per cent.	Green Strength (R.D.=1.6). Lb. per sq. in.	Dry Strength. (R.D.=1.6). Lb. per sq. in.
Facing sand ..	6.0	4.2	63
3 per cent. Bentonite	2.0	5.8	65
5 per cent. Colloidal Clay A	2.0	5.0	35
5 per cent. Fireclay No. 3 ..	2.3	5.0	20
5 per cent. Fireclay No. 6 ..	2.3	5.0	8
5 per cent. Ball Clay A ..	2.3	5.1	10
5 per cent. Ball Clay C ..	2.3	4.0	6
5 per cent. China Clay A ..	2.3	3.5	5

Table VI gives the dry strengths at the moisture percentage at which these particular sands would be used for green sand moulding. A used green sand facing sand made from a natural Bromsgrove moulding sand and containing coal dust is included for comparison, the moisture content being 6.0 per cent., a normal value for a natural sand of this type.

In order to compare these figures with Dietert's figures obtained by the A.F.A. method, a synthetic sand containing 5 per cent. fireclay No. 4 and 2.26 per cent. moisture was tested by both methods, with the following results.

	Dry strength.
B.C.I.R.A. method (R.D.=1.6) ..	6 lb. per sq. in.
A.F.A. method	6.7 lb. per sq. in.

It is clear from Table VI that while the first six sands have approximately the same green strengths, the dry strengths of the synthetic sands are, with the exception of the 3 per cent. bentonite mixture, considerably less than those of the natural moulding sands. The dry strengths of the sands bonded with 5 per cent. of the ball or fireclays and not containing coal dust are considerably less than the values specified by Dietert and Hudson. It would appear that this low dry strength is indirectly responsible for the opposition to synthetic sand by some hand moulders, since the synthetic sand made by combining a clay of this type with a highly permeable sand dries off at the surface more rapidly than a natural moulding sand, giving a friable surface which is not readily patched or "sleeked."

A practical trial was made in the foundry to ascertain whether satisfactory synthetic sands could be prepared with the fireclays or ball clays, in spite of the low dry strength. The sand consisted of Southport sand with 7 per cent. fireclay No. 6, 6 per cent. coal dust, milled for 10 min. and tempered to 3.2 per cent. moisture. No difficulty was experienced by the hand moulder in ramming this sand and an iron box was successfully cast in the mould. An extended trial was not made. It appears that synthetic sands containing fireclays of this type are usable, but careful control of the moisture content is necessary.

The incorporation of coal dust in a sand produces a considerable increase in the dry strength amounting in some cases to as much as 50 per cent. The increase occurs after the sand has been in use for moulding several times, the effect being probably related to the formation of tarry products in the sand. The utilisation of synthetic sands containing fireclay is thus extended when coal dust is used.

The change in the dry strength after the sand has been in use for some time for making castings was investigated in durability trials carried out by the Association. The synthetic sands consisted of Erith silica sand with 3.5 per cent. bentonite and 7 per cent. colloidal clay respectively. The dry strength of the former fell from 45.5 lbs. per sq. in. (A.F.A.) to 19.1 lbs. per sq. in. after fourteen castings and the latter from 22.6 to the low value of 2.5 lbs. per sq. in. A similar series in which coal dust was used with the latter sand showed, however, a much smaller decrease.

Refractoriness

The moulding sand in contact with the molten metal has to withstand for a short time a high temperature which causes considerable changes in its physical and chemical properties. The sand actually in contact with the metal may fuse or burn on to it if its fusion point is not sufficiently high, while the sand slightly further away loses its bond.

In a mechanised foundry the used sand is continually re-bonded by further additions of clay. An inferior bonding clay may thus exert a cumulative deleterious influence on the moulding sand and if readily fusible impurities are present in the clay they will accumulate in the moulding sand and progressively decrease the refractoriness.

TABLE VII.—*Fusion Points of Various Bonding Clays.*

Clay.	Fusion Point.
Colloidal Clay A ..	Exceeds 1,450 deg. C.
Ball Clay A	Exceeds 1,430 deg. C.
Ball Clay B	Exceeds 1,450 deg. C.
Fireclay No. 6 ..	Exceeds 1,430 deg. C.
China Clay A	Exceeds 1,450 deg. C.
Bentonite	1,330 deg. C.
Bentonite No. 2 ..	1,270 deg. C.

The fusion points of the bonding clays, determined by the Sinnatt apparatus, are given in Table VII. The fusion points are here the temperatures at which the thread of clay bends over.

For comparison the fusion points of the clay grade contained in various natural moulding sands are given below.

Sand.	Fusion Point of Clay Grade.
Erith—Medium Loam ..	1,315 deg. C.
Pickering	1,270 deg. C.
Bromsgrove — Middle Bed	1,390 deg. C.
Scottish—Greenfoot ..	1,400 deg. C.

The refractoriness of bentonite is lower than that of the other bonding clays, and is of the same order as that of the clay bonds in natural moulding sands. The reason is apparent from the chemical analysis (Table VIII), the percentage of Fe_2O_3, MgO and combined alkalis all being greater than in the case of the ball and china clays.

Burning-on of the sand is the chief defect that may result from the use of a clay of low refractoriness. The question is not one that has been investigated, however, and other factors which have not been studied appear to be involved, such as the refractoriness of the base sand, ease of penetration of the metal between the sand grains, and the surface skin on the molten metal. Two cases may be distinguished, according as to whether the moulding sand is used with coal dust or not.

Coal dust is added to moulding sand to prevent burning on and give a smoother finish. Its function is not fully understood, although considerable work has been done by Hird,[5] Winterton[6] and others. It is possible that the volatile matter driven off is decomposed by contact with the iron, coating the latter with a thin sooty layer, preventing the sand grains from burning on to the metal; the pressure of the gases evolved may also prevent penetration of the metal between the grains. Where coal dust is added, the refractoriness of the bonding clay is of minor importance in comparison with that of the coal ash accumulating. A typical coal dust of British origin[7] may give 5 per cent. of ash, with a fusion point between 1,200 and 1,450 deg. C. and analysing 43 per cent. silica, 31 per cent. Al_2O_3, 15 per cent. Fe_2O_3, 4 per cent. CaO and 5 per cent. other bases.

Synthetic sands without coal dust are in use. It was found that a synthetic sand, consisting of Frankley sand with 5 per cent. of colloidal clay A, burnt on badly when castings were made in it, except when the molten metal was poured cold. Replacing the Frankley sand with Erith silica or Leighton Buzzard No. 26A silica sand gave synthetic sands which did not burn on to the casting, an improvement explained by the higher refractoriness of these silica sands in comparison with the Frankley sand, which contains appreciable amounts of felspar and micaceous impurities. These Erith or Leighton Buzzard sands, when bonded with 3.5 per cent. of bentonite, also gave no burning on, in spite of the lower fusion point of the bentonite.

In the case of a constant sand cycle, the same sand is continually rebonded with further additions of clay. The effect of successive castings on a moulding sand has been under investigation in the durability tests, and is believed to take place along the following lines. At temperatures of 500 deg. C. and above, the bonding clay loses its combined water and cannot be made plastic again. At much higher temperatures near the fusion point, the clay, being in contact with the grains of silica sand, will soften and fuse at the eutectic temperature of the alumina, silica and flux mixture. In the mould the temperature of the sand falls rapidly as the distance from the hot metal increases, and fusion of the bonding clay will only occur in the layer nearest to the casting, and if the clay has a sufficiently low softening point. A considerable portion of the sand is exposed to temperatures of 500 deg. C. and above, however, and the dehydrated clay may behave in two ways—(1) fall off the sand grains, or (2) vitrify or burn on to the sand grains, since clays harden or vitrify at temperatures considerably below their fusion point.

The type of bonding clay probably decides which alternative actually occurs, but in the durability experiments it was established that colloidal clay A vitrified or burnt on to the sand grains, though the increase in silt percentage suggested that a part of the clay became detached from the sand. The film of burnt clay will have the same composition and refractori-

ness as the bonding clay itself, and it may be assumed that the tendency of the sand to burn on to the casting, when no coal dust is present, depends on the softening point of this film of clay and on its thickness. The thickness gradually increases as the used sand is continually rebonded with fresh clay.

TABLE VIII.—*Chemical Analysis of the Clays.*

	China clay A.	China clay B.	Ball clay A.	Ball clay C.	Colloidal clay A.	Fireclay. No. 1.	Fireclay. No. 2.	Fireclay. No. 3.	Fireclay. No. 6.	Fireclay (Scottish).	Red clay (Bromsgrove).	Bentonite.
SiO_2 ..	55.94	45.50	48.70	50.77	60.44	53.08	70.40	45.10	41.38	52.3	53.76	61.51
Al_2O_3 ..	29.55	38.42	34.77	33.65	19.20	29.79	19.74	33.46	29.06	30.5	25.39	22.09
Fe_2O_3 ..	1.25	0.75	1.37	1.25	3.31	2.01	1.60	2.50	2.14	2.5	6.94	4.16
CaO	1.10	0.60	0.47	0.93	1.59	1.20	0.53	1.20	1.20	0.5	0.34	1.74
MgO ..	0.61	0.67	0.22	0.57	1.01	0.76	1.00	0.94	0.81	0.6	2.06	2.87
TiO_2 ..	1.50	0.60	1.05	1.35	0.97	1.50	1.38	1.55	1.30	1.1	0.62	0.22
K_2O ..	0.80	} 1.05	1.64	1.20	{ 0.68	} 0.69	1.01	{ 0.66	} 1.73	—	3.12	1.56
Na_2O ..	0.99				{ 0.27			{ 0.17				
Loss on ignition	9.12	13.07	11.68	10.23	10.36	11.40	4.08	14.60	22.00	12.0	7.77	5.77
SiO_2/Al_2O_3	3.2	2.01	2.3	2.5	5.3	3.0	6.0	2.3	2.4	—	—	4.7
*p*H value ..	6.33	5.14	3.48	5.10	5.43	—	7.51	7.53	6.92	—	—	9.0

The synthetic sand containing 3.5 per cent. of bentonite showed no burning-on, but it appeared possible that, owing to the fusion point of bentonite being 1,330 deg. C., some burning-on might be experienced where the used sand was being rebonded and a thick film of burnt bentonite had accumulated on the sand grains. To test this possibility, a synthetic sand was made of Erith silica sand with 20 per cent. of bentonite, the mould skin-dried and molten metal poured in. In spite of the thick clay film coating the sand grains no burning-on took place, and the sand readily fell off the casting. The use of bentonite thus appears satisfactory, even in the absence of coal dust.

Properties of the Clays and Relation to Bonding Power

The clays show large differences in tensile strength and in bonding power. Some of the purest clays—the china clays—show the lowest bonding power, and it is clear that the differences can only in part be attributed to the presence of natural diluent impurities such as silica. The fundamental properties of the clays responsible for these differences were therefore investigated, as it appeared possible that the bonding power of the clay might be increased by appropriate treatment.

The chemical analyses of the clays are given in Table VIII, and include a red (iron-rich) clay extracted from a natural Bromsgrove moulding sand. The molecular silica to alumina ratio and the *p*H values of the clays (determined by the hydrogen electrode) are also given.

The analyses of carefully purified china clays correspond to the formula $Al_2O_3 . 2SiO_2 . 2H_2O$ (china clay B corresponds to $Al_2O_3 . 2.01\ SiO_2 . 1.93\ H_2O$), which is that of the mineral kaolinite, and it was at one time held that all clays have as basis this clay substance and that silica in excess of the two to one ratio to alumina is present as free silica. This view does not explain the poor bonding power of the pure china clays, and it is now recognised that the clays may contain minerals other than kaolinite as their clay substance. The properties of bentonite are markedly different from English clays, *i.e.*, the small loss on ignition and base exchange properties, and Ross and Shannon[8] suggested that the clay substance consisted of montmorillonite. Its identity with this mineral $Al_2O_3 . 4SiO_2 . H_2O$ has been confirmed by X-ray analysis.[9] The iron-rich clay from the natural moulding sand also shows marked differences from the kaolins.

The clays in general consist of extremely fine particles which cohere strongly when the clay is made plastic with water. The particles are disc-shaped, which is probably the reason for the high plasticity of clays compared with other solid powders. The suspension in water behaves as a colloid, the particles being negatively charged and having effective diameters less than 10 microns (1 micron = 0.001 mm.).

The particle sizes were measured by the sedimentation method of Vinther and Lasson,[10] using a 0.002 M sodium pyrophosphate solution for obtaining maximum deflocculation. The suspensions were made up of the 0.002 M pyrophosphate solution with 2 per cent. of clay and agitated for 16 hours in a shaking machine revolving at 85 revolutions per minute. The results expressed as the percentage weights of clay less than 10, 2 and 0.5 microns diameter are given in Table IX.

TABLE IX.—*Particle Size Analysis.*

	10μ	2μ	0.5μ
China Clay B	83.0	56.6	24.6
China Clay A	92.6	72.8	47.2
Fireclay No. 6	50.5	37.8	17.2
Ball Clay A	99.0	94.0	81.0
Colloidal Clay A ..	88.3	67.6	53.4
Bentonite	98.4	92.5	80.8

Bentonite and ball clay A have the greatest percentage of fine material less than 0.5 micron diameter, and it is clear that there is a rough relation between this percentage and the bonding power of the clay. Fireclay No. 6 is an exception to this rule, although this may possibly be due to the presence of coarse clay aggregates in the suspension, since the clay has a gritty feeling when moistened, and only after rubbing does the full plasticity develop and the grittiness disappear.

A more exact relation was found between the bonding power and the quantity of water adsorbed by the clays when exposed to atmosphere humidity. The results are given in Table X. The dry strengths are also given (initial moisture 2.3 per cent. with the exception of the red clay) and the water adsorption seems to show an even closer relation with this property.

TABLE X.—*Showing Relation between Moisture Adsorption and Bonding Power.*

Bonding clay.	Water adsorbed per 100 gm. Clay.	Optimum Green Strength.	Dry Strength.
Bentonite (3 per cent.	12.86	13.8	100
Ball Clay A ..	3.63	6.1	10
Colloidal Clay A ..	5.46	5.7	40
Fireclay No. 6 ..	3.96	5.15	8
Natural Red Clay ..	6.30	5.0	(40)
Ball Clay C ..	2.32	4.2	6
China Clay A ..	1.94	3.6	5
China Clay B ..	1.40	2.9	—

On theoretical grounds, the quantity of water adsorbed under these conditions would be expected to depend on (1) the total surface area of the clay particles, and (2) the force of attraction between the surface and the water—a strong attraction resulting in a comparatively thick film of adsorbed water. These considerations and the relation found enable one to form a clearer view, on the following lines, of the factors governing tensile strength of moist clay and thus the bonding power.

Owing to its high adsorptive power, the clay particle has a strong attraction for water, and when moistened surrounds itself with a firmly attracted water film. If the water is not sufficient for the complete saturation of the adsorption forces, adjacent clay particles with their water envelopes are strongly attracted, resulting in a firmly coherent mass of clay. The tensile strength of the moist clay will thus depend on the amount of water present and the adsorptive power of the clay for water. The tensile strength may be considerable if slip between adjacent layers of clay, due to the applied forces, is prevented. The ease with which slip between adjacent layers may take place will depend on the viscosity of the aqueous medium between the particles, a relationship which is demonstrated in the high tensile strength obtained by kneading a clay with a viscous liquid such as molasses. Regarding the clay, for simplicity, as a mixture of coarse and very fine particles, the aqueous medium between the coarse particles may be regarded as consisting of the colloidal suspension of very fine particles. The viscosity of a colloidal suspension is known to depend on the amount of colloidal material, the electric charge on the particles, and to be inversely dependent on the diameter of the particles, *i.e.*, the smaller the particle size, the greater the viscosity. Considering all these factors, it may be concluded that the tensile strength of the moist clay and the bonding power depend on (1) the purity of the clay and the absence of silica impurities; (2) the adsorptive power of the clay for water; (3) the fineness of the particle size and the electric charge; and (4) the chemical composition of the clay substance or clay substances, if more than one be present.

Comparison of Natural and Synthetic Sands

The natural moulding sands show marked differences from the synthetic sands discussed. A Bromsgrove natural moulding sand will be actually used at about 6 per cent. moisture, which is considerably higher than in the case of synthetic sands; it has a lower permeability than the latter, and has a good dry strength. These differences may be attributed to (1) differences in the sizes and surface properties of the sand grains; and (2) the particular clay in the natural moulding sand. The results obtained by combining the red clay extracted from the natural moulding sand with the same base silica sand used for the preparation of the synthetic sands, so as to eliminate (1), were thus of particular interest.

The green strength figures for this pseudo synthetic sand are given in Table I. It was found that the percentage of moisture required was higher, since at 2.26 per cent. moisture, a suitable figure for the other synthetic sands, the sand felt too dry for satisfactory moulding. A moisture percentage of 3.6 appeared most satisfactory; in comparison, the other synthetic sands felt wet and sticky, and would have stuck to the pattern at this moisture content. The dry strength of 40 lbs. per sq. in. (Table V) is greater than the other synthetic sands, with the exception of the 3 per cent. bentonite mixture, making the comparison at the moisture contents suitable for green sand moulding.

The results show that the characteristic features of Bromsgrove moulding sand—(1) large percentage of water required; (2) flat topped green strength : moisture curves; and (3) good dry strength—are due mainly to the particular type of clay present in the sand.

The lower moisture content of synthetic sands gives them an advantage over natural mould-

(*Continued at foot of facing page.*)

THE THERMAL CONDUCTIVITY OF HIGH-DUTY AND ALLOY CAST IRONS

BY J. W. DONALDSON,* D.Sc.

1. Introduction

The thermal conductivity of grey cast iron was determined by the author[1] some ten years ago in a series of investigations covering a wide range of cast irons. Experiments were also made to determine the influence on the thermal conductivity of grey cast iron of certain alloy additions. All the determinations were carried out over a range of temperature from 50 to 500 deg. C. As a result of these investigations, it was shown that the thermal conductivity of grey cast iron varied from 0.110 to 0.137 cal. per cm. per sec. and decreased as the temperature increased. The values obtained for thermal conductivity depended not only on the composition but also, although to a much smaller extent, on structure, free ferrite being a much better conductor of heat than eutectoid pearlite. The influence of silicon was to lower the conductivity considerably, but with over 2 per cent. of silicon the falling-off in conductivity was reduced, owing to the formation of a ferrite structure. Phosphorus tended to produce a slight decrease in thermal conductivity, and manganese had a somewhat similar effect. As regards alloy additions, nickel produced a similar effect to silicon. Vanadium had little influence, while chromium and tungsten tended to raise the conductivity. Heat-treatment at 550 deg. C. at first increased the thermal conductivity due to pearlite decomposing to form ferrite and graphite, after which oxidation of iron in the vicinity of the graphite flakes caused a slight decrease.

Since these investigations were carried out, considerable advances have taken place in the metallurgy of cast iron, and have resulted in the development of the high-duty and alloy cast irons. As it had been found that alloy additions exerted an important influence on the heat-conductivity property of cast iron, it was considered of interest to investigate this property in those newly developed irons with a view not only of determining the effect of the combination of alloying elements already experimented with, but also to determine the effect of new alloying elements, while at the same time obtaining reliable data on the thermal conductivity of such irons.

2. Composition of Cast Irons Tested

The first series of cast irons tested consisted of two unalloyed or plain cast irons and two alloy cast irons. The former were cast from two hematite and steel base mixtures and contained varying amounts of silicon and manganese. To the lower silicon iron copper was added, and to the higher silicon iron additions of chromium and molybdenum were made. The compositions of the four irons are given in Table I. All the irons were cast in bars 20 in. long by 0.875 in. dia. and were poured in green-sand moulds.

The second series of cast irons tested are commercial high-duty cast irons, and include an unalloyed cast iron, a molybdenum iron, a manganese-nickel iron, a nickel-chromium iron, and a Ni-Tensyl iron. The compositions of these irons, which were cast in 1.2-in. dia. bars in dry-sand moulds, are given in Table II, together with their tensile strengths.

TABLE I.—*Composition of Plain and Alloy Cast Irons.*

Cast iron.	Plain 1.	Copper.	Plain 2.	Chromium molybdenum
	Per cent.	Per cent.	Per cent.	Per cent.
T.C ..	3.20	3.18	3.11	3.12
Si ..	1.56	1.58	2.26	2.31
Mn ..	0.72	0.69	0.39	0.38
Cr ..	—	—	—	0.54
Cu ..	—	1.58	—	—
Mo ..	—	—	—	0.77

TABLE II.—*Composition of High-Duty Cast Irons.*

Cast iron.	Plain.	Molybdenum.	Ni-Tensyl.	Manganese nickel.	Nickel chromium.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
T. C ..	2.61	2.56	2.80	3.10	3.41
Si ..	2.46	2.20	2.51	2.51	1.03
Mn ..	0.45	0.63	0.68	3.11	0.65
Ni ..	—	—	1.71	1.00	1.49
Cr ..	—	—	0.54	—	0.54
Mo ..	—	0.58	—	—	—
Tensile strength tons per sq. in. ..	22.7	25.4	25.0	24.7	21.5

The heat-resisting cast irons Ni-Resist and Nicrosilal, together with an aluminium-chromium cast iron, formed the third series of irons tested, and their compositions are given in Table III.

TABLE III.—*Composition of Heat-Resisting Cast Irons.*

Cast iron.	Ni-Resist.	Aluminium-chromium.	Nicrosilal.
	Per cent.	Per cent.	Per cent.
T. C ..	2.41	2.70	1.81
Si	1.80	0.96	6.42
Mn	0.62	0.58	—
Ni	13.70	—	18.65
Cr	3.37	0.95	2.02
Cu	6.41	—	—
Al	—	7.00	—

3. Apparatus Used and Method of Manipulation

The apparatus used in determining the thermal conductivity, a sketch of which is given in Fig. 1, has already been described in various Papers, so that only a brief description is now necessary. It is an apparatus based on the familiar guard-ring method of determining conductivity, designed for use in a commercial laboratory, and combines fair accuracy with fairly rapid manipulation. The flow of heat is measured by three thermocouples, placed 4 in. apart in a test-bar 15.5 in. long by 0.75 in. in diameter. The test-bar is heated by means of an electric heater, and the amount of heat flowing through the bar is measured by means of a continuous flow calorimeter. Lateral loss of heat is compensated for by an insulated guard-ring heated and cooled in a similar manner to the test-bar. Determinations were made over a range of temperature varying from 40 to 530 deg. C., copper-con-

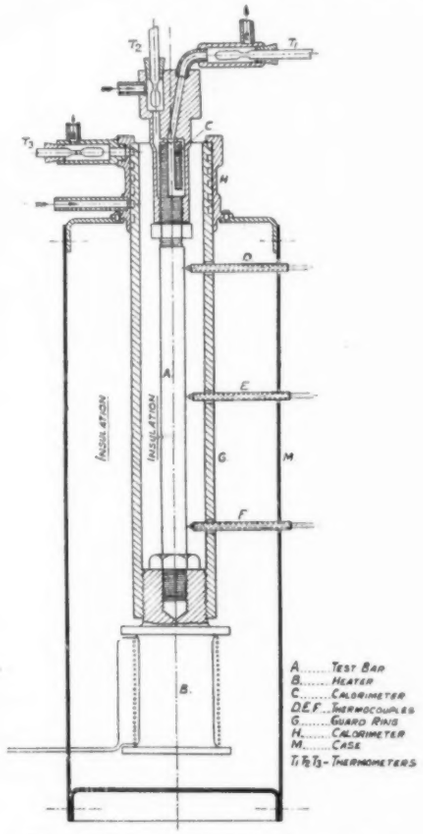


FIG. 1.—APPARATUS FOR DETERMINING THERMAL CONDUCTIVITIES.

* Scotts' Shipbuilding and Engineering Company, Limited, Greenock.

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ing sands, as less steam is generated during casting. In changing over from natural to synthetic moulding sands, the moisture content has to be carefully controlled, since in general the dry strengths are lower than in the case of natural moulding sands and evaporation losses from the hot moulding sand are high when the synthetic sand is prepared from a highly permeable silica sand.

The use of bentonite appears advantageous in that the synthetic sands bonded with it combine many of the good points of the natural moulding sands in regard to dry strength and small variation in properties with moisture content, *i.e.*, greater latitude. The durability is also satisfactory. On the other hand, colloidal clay A occurs naturally in the British Isles, and thus uninterrupted supplies are available. As an alternative, the more plastic fireclays are suitable, provided that due regard is made to their lower dry strength. Trials showed that there is no advantage in grinding these fireclays finer than 60 mesh.

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stantan thermocouples being used for the lower temperature measurements and platinum-rhodium for the higher temperatures. The thermometers used were standard ones reading to 0.05 deg. C.

The thermal conductivity K was calculated by the formula:

$$K = \frac{W\,(t_1 - t_2)\,l}{(T_1 - T_2)\,a}$$

Where

W = weight of water in grm. flowing through calorimeter C;
t_1 = temperature of outlet water from C in deg. C.;
t_2 = temperature of inlet water to C in deg. C.;
T_1 = temperature of the hotter thermocouple in deg. C.;
T_2 = temperature of the colder thermocouple in deg. C.;
l = distance between the thermocouples in cms.;
a = cross-sectional area of the bar in sq. cms.

Determinations for each iron were made over five varying temperature ranges, and a period of six hours was allowed at each range to obtain a heat balance and to establish equilibrium conditions. Three sets of readings were taken, and the average values obtained were used in calculating the thermal conductivities for the two different temperature ranges measured.

The various sources of error which may occur in using this apparatus have been very fully considered and a detailed description of the methods adopted to check them has been published.[2] When such sources of error are considered, they show that, provided the test-bar is made to accurate dimensions and the apparatus is properly manipulated, the results obtained cannot vary by more than 2 per cent. As an additional check on the apparatus and the accuracy of the thermocouples and thermometers, a commercially-pure aluminium test-bar, kept specially for calibration purposes, was tested before and after the determinations of each series of irons.

4. Consideration of Results

The results of the determinations for the various cast irons are given in Tables IV to XV. Curves plotted from these determinations showing the variation of thermal conductivity with the mean temperature for each of the three series of cast irons are given in Figs. 2 to 4. In Table XVI are given the thermal conductivity values at 100 and 400 deg. C. of unalloyed and alloyed cast irons determined in a previous investigation[1] and in Table XVII the thermal conductivity values at similar temperatures of all the irons experimented with in the present investigation.

TABLE IV.—*Plain Cast Iron.* I.

Test.	Temperature range. Deg. C.	Mean temperature. Deg. C.	K.
1	51–118	84.5	0.122
	118–187	152.5	0.118
2	74–154	114.0	0.121
	154–237	195.5	0.117
3	130–252	191.0	0.117
	252–382	317.0	0.111
4	144–306	225.0	0.115
	306–480	393.0	0.107
5	160–334	247.0	0.115
	334–520	427.0	0.107

Consideration of the data in these two tables and of the curves in Figs. 2 to 4 shows the unalloyed iron P1 to have a somewhat similar heat-conducting value to the unalloyed iron S8 previously determined which contained approximately the same amount of silicon. The addition of 1.58 per cent. of copper lowers the conductivity of the former iron from 0.121 to 0.112 at 100 deg. C. with a proportional decrease at 400 deg. C. The plain iron P, which is of lower carbon content and higher silicon content than P1, has a thermal conductivity of 0.110 at 100 deg. C., due to its higher silicon content, a value somewhat similar to that obtained with the plain iron P2, which contains slightly lower silicon but a higher carbon content. The thermal conductivity of P is increased to 0.118 by an addition of 0.58 per cent. of molybdenum, and that of P2 is raised to approximately the same value by an addition of 0.54 per cent. of chromium and 0.77 per cent. of molybdenum.

FIG. 2.—THERMAL CONDUCTIVITIES OF PLAIN AND ALLOY CAST IRONS.

The results obtained from these five cast irons show that copper lowers the thermal conductivity of cast iron in a similar manner to silicon and nickel. Its influence, however, is not so marked as that of silicon or nickel. In Fig. 5 is shown the influence of silicon in lowering the thermal conductivity of cast iron, as determined by the author[3] in a previous investigation, where experiments were made on a series of cast irons containing 0.65 to 6.49 per cent. silicon. From this curve it appears that 0.8 per cent. of silicon lowers the thermal conductivity approximately 0.01, while the present determination with copper shows that twice the amount of this element is required to produce the same effect. As regards the influence of nickel, reference to Table XVI shows that a nickel addition of 0.75 per cent. produces a fall in thermal conductivity of 0.013 or approximately 10.5 per cent. The influence of copper in lowering the heat-conducting property of cast iron would therefore appear to be less than half that of silicon, while the influence of nickel is probably 30 per cent. more than that of silicon.

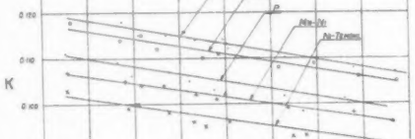


FIG. 3.—THERMAL CONDUCTIVITIES OF HIGH-DUTY CAST IRONS.

FIG. 4.—THERMAL CONDUCTIVITIES OF HEAT-RESISTING CAST IRONS.

The influence of molybdenum is to raise the thermal conductivity of cast iron in a similar manner to chromium and tungsten. Its influence, however, is not so marked as in the case of these elements, for when the values given in Tables XVI and XVII are considered it is observed that a similar rise in thermal conductivity of approximately 7.3 per cent. is produced by 0.4 per cent. of chromium, 0.5 per cent. of tungsten, or 0.6 per cent. of molybdenum. Alloying of the two elements, chromium and molybdenum, in cast iron in proportions of 0.54 and 0.77 per cent. does not appear to produce a very much greater increase in conductivity, as the value obtained for the chromium-molybdenum iron at 100 deg. C. is only 8.2 per cent. higher than in the corresponding unalloyed iron.

TABLE V.—*Copper Cast Iron.*

Test.	Temperature range. Deg. C.	Mean temperature. Deg. C.	K.
1	47–120	83.5	0.113
	120–195	157.5	0.109
2	80–189	134.5	0.112
	189–302	245.5	0.108
3	107–236	171.5	0.110
	236–368	302.0	0.105
4	136–304	220.0	0.108
	304–478	391.0	0.104
5	152–331	241.5	0.105
	331–518	424.5	0.100

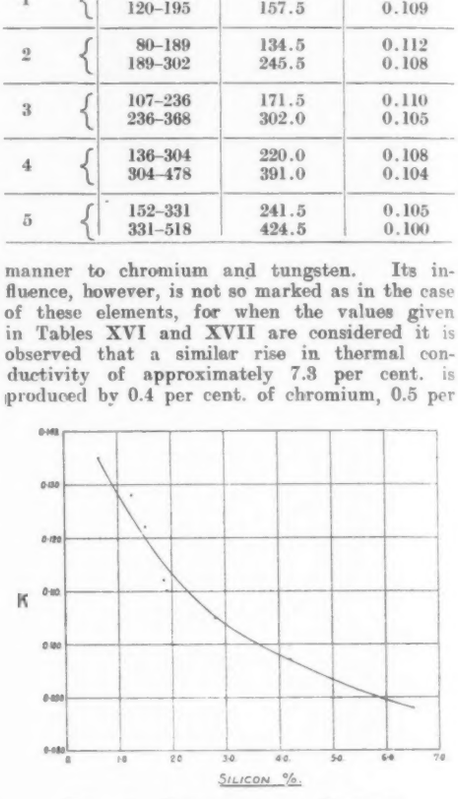


FIG. 5.—VARIATION OF THERMAL CONDUCTIVITY WITH SILICON.

TABLE VI.—*Plain Cast Iron.* 2.

Test.	Temperature range. Deg. C.	Mean temperature. Deg. C.	K.
1	51–122	86.5	0.110
	122–196	159.0	0.106
2	85–192	138.5	0.109
	192–303	247.5	0.105
3	114–242	178.0	0.108
	242–375	308.5	0.104
4	133–302	217.5	0.108
	302–478	390.0	0.103
5	143–327	235.0	0.105
	327–518	422.5	0.100

The thermal conductivity values for the high duty irons, Ni-Tensyl, manganese-nickel, and nickel-chromium indicate the influence which the special element additions in combination with silicon have on the heat-conducting property of these materials. The Ni-Tensyl and the man-

ganese-nickel cast irons have similar silicon contents to the plain iron P. The thermal conductivity values of the three irons at 100 deg. C. are 0.101, 0.106, 0.110. The decrease in conductivity in the Ni-Tensyl iron is produced by the addition of 1.71 per cent. of nickel and in the manganese-nickel iron by the 1.0 per cent. of nickel. In view of what has been indicated of the influence of nickel in lowering the thermal conductivity of cast iron a larger decrease might have been expected in both irons. The addition of chromium in the one iron and of manganese in the other appears to have had a beneficial effect in counteracting the full influence of the nickel. A somewhat similar result is obtained with the nickel-chromium iron. This iron on account of its lower silicon content cannot be compared with the unalloyed iron P, but if the value for an unalloyed iron containing 1 per cent. of silicon is derived from Fig. 5 and is taken as 0.127, the influence of the nickel addition of 1.49 per cent. in lowering the conductivity and the counteracting effect of the 0.54 per cent. of chromium are seen in the value of 0.116 obtained at 100 deg. C.

The influence of special elements in lowering the thermal conductivity of cast iron is also seen to a more marked degree when the values obtained for the three irons in the third series are considered. The Nicrosilal containing approximately 18.5 per cent. of nickel and 6.5 per cent. of silicon has a value of 0.070 at 100 deg. C. Replacing part of the nickel by copper and reducing the silicon content, as is done in the Ni-Resist, raises the heat-conducting value of the iron by 15 per cent., a conductivity of 0.081 being obtained at 100 deg. C. A somewhat similar value of 0.079 at 100 deg. C. is obtained

TABLE VII.—*Chromium-Molybdenum Cast Iron.*

Test.	Temperature range. Deg. C.	Mean temperature. Deg. C.	K.
1	43–115	79.0	0.121
	115–189	152.0	0.118
2	87–197	142.0	0.118
	197–309	253.0	0.115
3	115–242	178.5	0.116
	242–374	308.0	0.112
4	139–307	223.0	0.114
	307–483	395.0	0.110
5	159–339	249.0	0.113
	339–528	433·5	0·108

TABLE VIII.—*Low-Carbon Cast Iron.*

Test.	Temperature range. Deg. C.	Mean temperature. Deg. C.	K.
1	40–111	75.5	0.110
	111–185	148.0	0.106
2	80–186	133.0	0.109
	186–296	241.0	0.105
3	117–246	181.5	0.107
	246–380	313.0	0.102
4	126–294	210.0	0.104
	294–468	381.0	0.101
5	146–330	238.0	0.103
	330–520	425.0	0.099

TABLE IX.—*Molybdenum Cast Iron.*

Test.	Temperature range. Deg. C.	Mean temperature. Deg. C.	K.
1	47–118	82.5	0.118
	118–191	154.5	0.115
2	84–191	137.5	0.118
	191–302	246.5	0.114
3	122–248	185.0	0.115
	248–380	314.0	0.110
4	134–302	218.0	0.114
	302–478	390.0	0.108
5	162–341	251.5	0.112
	341–530	435.5	0.107

TABLE X.—*Ni-Tensyl Cast Iron.*

Test.	Temperature range. Deg. C.	Mean temperature. Deg. C.	K.
1	38–114	76.0	0.103
	114–192	153.0	0.100
2	87–196	141.5	0.099
	196–308	252.0	0.096
3	120–254	187.0	0.098
	254–392	323.0	0.093
4	129–300	214.5	0.096
	300–476	388.0	0.093
5	133–324	228.5	0.095
	324–521	422.5	0.091

TABLE XI.—*Manganese-Nickel Cast Iron.*

Test.	Temperature range. Deg. C.	Mean temperature. Deg. C.	K.
1	45–120	82.5	0.107
	120–197	158.5	0.104
2	86–194	140.0	0.105
	194–305	249.5	0.102
3	116–248	182.0	0.104
	248–385	316.5	0.099
4	132–302	217.0	0.102
	302–477	389.5	0.098
5	146–335	240.5	0.101
	335–531	433.0	0.096

TABLE XII.—*Nickel-Chromium Cast Iron.*

Test.	Temperature range. Deg. C.	Mean temperature. Deg. C.	K.
1	44–119	81.5	0.118
	119–190	154.5	0.115
2	81–188	134.5	0.114
	188–298	243.0	0.111
3	110–241	175.5	0.112
	241–376	308.5	0.108
4	141–308	224.5	0.110
	308–481	394.5	0.106
5	153–340	246.5	0.109
	340–534	437.0	0.105

TABLE XIII.—*Ni-Resist Cast Iron.*

Test.	Temperature range. Deg. C.	Mean temperature. Deg. C.	K.
1	35–113	74.0	0.082
	113–194	153.5	0.079
2	76–186	131.0	0.081
	186–299	242.5	0.079
3	104–239	171.5	0.079
	239–379	309.0	0.076
4	129–297	213.0	0.079
	297–471	384.0	0.075
5	149–333	241.0	0.078
	333–524	428.5	0.074

TABLE XIV.—*Aluminium-Chromium Cast Iron.*

Test.	Temperature range. Deg. C.	Mean temperature. Deg. C.	K.
1	44–123	83.5	0.080
	123–205	164.0	0.078
2	80–193	136.5	0.078
	193–307	250.0	0.077
3	106–242	174.0	0.078
	242–382	312.0	0.075
4	127–298	212.5	0.077
	298–474	386.0	0.074
5	144–333	238.5	0.075
	333–527	430.0	0.072

TABLE XV.—*Nicrosilal Cast Iron.*

Test.	Temperature range. Deg. C.	Mean temperature. Deg. C.	K.
1	40–119	79.5	0.071
	119–199	159.0	0.070
2	82–195	138.5	0.069
	195–310	252.5	0.068
3	107–244	175.5	0.068
	244–385	314.5	0.065
4	132–303	217.5	0.066
	303–479	391.0	0.064
5	143–333	238.0	0.066
	333–528	430.5	0.063

TABLE XVI.—*Thermal Conductivities of Plain and Alloy Cast Irons at 100 and 400 deg. C.*

Mark.	Composition.							K.	
	T.C.	Si.	Mn.	Ni.	Cr.	V.	W.	100 deg. C.	400 deg. C.
S.8	3.16	1.48	0.97	—	—	—	—	0.122	0.108
S.9	3.25	1.91	0.97	—	—	—	—	0.110	0.103
Mn	3.32	1.52	2.43	—	—	—	—	0.118	0.101
Ni	3.16	1.56	0.94	0.75	—	—	—	0.108	0.101
Cr	3.17	1.40	0.97	—	0.39	—	—	0.131	0.114
V	3.19	1.45	0.99	—	—	0.124	—	0.122	0.103
W	3.02	1.89	0.76	—	—	—	0.475	0.118	0.105

TABLE XVII.—*Thermal Conductivities of Plain and Alloy High-Duty Cast Irons and Heat-Resisting Cast Irons at 100 and 400 deg. C.*

Mark.	Composition.								K.	
	T.C.	Si.	Mn.	Ni.	Cr.	Mo.	Cu.	Al.	100 deg. C.	400 deg. C.
P.1	3.20	1.56	0.72	—	—	—	—	—	0.121	0.108
Cu	3.18	1.58	0.69	—	—	—	1.58	—	0.112	0.101
P.2	3.11	2.26	0.39	—	—	—	—	—	0.111	0.101
Cr–Mo	3.12	2.31	0.39	—	0.54	0.77	—	—	0.119	0.109
P	2.61	2.46	0.45	—	—	—	—	—	0.110	0.100
Mo	2.56	2.20	0.63	—	—	0.58	—	—	0.118	0.108
Ni-Tensyl	2.80	2.51	0.68	1.71	0.54	—	—	—	0.101	0.092
Mn–Ni	3.10	2.51	3.11	1.00	—	—	—	—	0.106	0.097
Ni–Cr	3.41	1.03	0.65	1.49	0.54	—	—	—	0.116	0.106
Ni-Resist	2.41	1.80	0.62	13.70	3.37	—	6.41	—	0.081	0.075
Al–Cr	2.70	0.96	0.58	—	0.95	—	—	7.00	0.079	0.072
Nicrosilal	1.81	6.42	—	18.65	2.02	—	—	—	0.070	0.063

(*Continued at foot of next page.*)

CORE-SHOP CONTROL

By J. J. SHEEHAN,* B.Sc., A.R.C.Sc.I.

Adequate control of a core shop will consist of the control of materials, processes and mechanical operations. Under these headings the control may be extended to include the following items:—

(1) *Control of Materials*, which will include sands; binders; washes; pastes; chaplets; wires; parting powders; and the miscellaneous materials of a foundry stores.

(2) *Control of Processes*: for example, sand mixing; core baking; mixing, application and drying of washes; jointing of core assemblies; gauging and inspecting.

(3) *Control of Mechanical Operations*, such as the mechanical handling, transport and storage of raw materials and finished product; core blowing and core moulding; and sand recovery systems.

It would be difficult to cover the subject matter as extended above in a single Paper. The difficulty is avoided by making a selection, influenced by the fact that most attention is given to problems that arise in practice. It is therefore hoped that while the whole subject is not treated in detail, those items which are, will be of practical interest and value.

The foundry where the work in connection with this Paper was carried out is a motor vehicle foundry operating a steel, an iron and a non-ferrous section, and the materials used in the core shop are those common to foundries making light to medium-weight castings in steel, cast iron and non-ferrous metals.

CONTROL OF MATERIALS

Sands

Silica sands only are employed; no moulding sands or naturally-bonded sands are used in making cores. While it is realised that clay-bonded sands are used extensively particularly in the non-ferrous section of the industry, all the technique used in the foundry concerned has been built around silica sands bonded with organic binders, and these sands only will be considered.

Three types of sand are used, two extensively and one for special purposes. They are typified according to their grain size, and may be conveniently referred to as large, medium and fine sands, and are represented by the following:—

Large grain	...	Leighton Buzzard.
Medium grain	...	Somerford.
Fine grain	...	Arnold's 26A—Leighton Buzzard.

The exact chemical composition of these silica sands is not important when core making is the only end in view. As, however, the spent sands from the core knock-out are utilised as the base grain for synthetic moulding sand, and it is also intended ultimately to instal a core-sand recovery system, then the chemical composition will become of importance.

* Austin Motor Company, Limited, Birmingham.

A control process on the mixing platform is also influenced by the chemical composition. This process will be described later, but at present it is sufficient to mention that the absence of free lime and of calcium carbonate in the sand is necessary for the success of the process. The incorporation of burnt core sand in the steel and cast-iron moulding systems necessitates the use of as pure a silica sand as it is possible to obtain economically.

The chemical composition of the sands used is given below:—

Garside's Leighton Buzzard (Large Grain Sand).

	Per cent.
Loss on ignition	0.10
Silica	99.50
Ferric oxide	0.03
Alumina	0.26
Titanium dioxide	Nil
Lime	Nil
Magnesia	0.20
Alkalis	Nil

Somerford (Medium Grain Sand).

	Per cent.
Loss on ignition	0.45
Silica	94.66
Ferric oxide	0.45
Alumina	2.10
Titanium dioxide	0.08
Lime	0.58
Magnesia	0.20
Alkalis	1.61

Arnold's 26A (Unwashed).

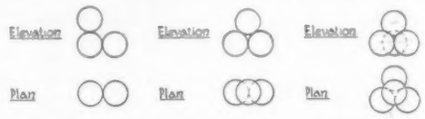
	Per cent.
Loss on ignition	0.72
Silica	96.20
Ferric oxide	0.25
Alumina	1.98
Titanium dioxide	0.05
Lime	0.03
Magnesia	0.15
Alkalis	0.72

The chemical composition of these sands influenced the selection for the reasons already given, but the main consideration in their ultimate adoption for use in the core shop is their grading or grain size. The grading of these sands is given in Table I.

TABLE I.—*Percentage Grading of Core Sands Used.*

I.M.M. Screens.	Leighton Buzzard.	Somerford.	Arnold's 26A.
+ 10	0.1	—	0.1
20	1.2	0.2	0.2
30	14.9	1.5	0.2
40	60.4	9.0	0.4
50	17.7	18.1	1.6
70	4.4	37.7	19.3
100	1.0	21.7	46.5
150	0.3	8.8	26.1
200	—	2.2	2.5
−200	—	0.6	1.2
Clay	—	1.1	2.2

Using this selection and balancing the proportions of each in the sand mixture, it is possible to obtain a measure of control of:—(*a*) The permeability of the cores; (*b*) the amount of binder used; (*c*) the finish on the castings (where external cores are used); (*d*) the tendency to give expansion cracks, and also to a considerable extent (*e*) to prevent sagging of the green core.



OPEN PACKING A. FIG. 1. OPEN PACKING B. FIG. 2. CLOSE PACKING C. FIG. 3.

All these factors are of considerable importance in the making of a good core, and are influenced basically by the grading and condition of the sand grains.

PLAN of OPEN-PACKED LAYER. FIG. 4. PLAN of CLOSE-PACKED LAYER. FIG. 5.

It is possible (with grading control) to regulate any one of the conditions mentioned above, but only at the expense of the others; for example, the permeability may be increased by increasing the size of the sand grains, but this increase is accompanied by a rougher finish on the castings. It is possible to maintain good permeability, with good finish, by using a fine round-grained sand, the grains being also uniform in size. The expansion troubles produced by this type of sand are, however, considerable.

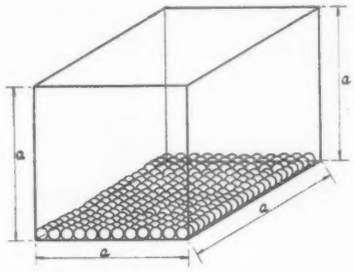


FIG. 6.

It is obvious that many and complex factors in this control must be taken into consideration, and that a unity of conception must be main-

(*Continued from previous page.*)

with the aluminium-chromium iron. This low value is produced in an iron containing a low percentage of silicon by the addition of 7.0 per cent. of aluminium, which would appear to indicate that aluminium has a very marked effect on the thermal conductivity of cast iron, an effect which is much greater than that produced by nickel.

5. Conclusions

The general conclusions to be formed from the above data may be summarised as follow:—

(1) The thermal conductivity of grey cast iron is lowered by copper in a similar manner to which it is lowered by silicon and nickel. The influence of copper, however, is approximately half that of silicon.

(2) Molybdenum tends to raise the thermal conductivity of grey cast iron, and in this respect acts in a similar manner to chromium and tungsten, although its influence is not so pronounced.

(3) Where nickel and chromium or nickel and manganese are alloyed together in cast iron, the influence of nickel in lowering the thermal conductivity is counteracted to a slight degree by the chromium or manganese.

(4) A large proportion of nickel has a pronounced influence in lowering the thermal conductivity of cast iron, but where part of the nickel is replaced by copper, the influence is not so marked.

(5) Aluminium, even in the presence of chromium, has a very pronounced influence in lowering the thermal conductivity of grey cast iron.

The author's thanks are due to Mr. J. Brown, C.B.E., and the other directors of Scotts' Shipbuilding & Engineering Company, Limited, of Greenock, for permission to carry out the above investigations. He also wishes to thank Mr. J. Arnott, F.I.C., of G. & J. Weir, Cathcart; Dr. A. B. Everest, of the Mond Nickel Company, Limited, London; and Mr. J. G. Pearce, M.Sc., of the British Cast Iron Research Association, for the samples of the various cast irons tested.

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2 J. W. Donaldson. "Metallurgia," 1930, Vol. I, pp. 151-154.
3 J. W. Donaldson. Journal of the Iron and Steel Institute, 1933, Vol. 78, pp. 255-274.

three "fitting-in" sizes—the 0.414*d*, 0.22*d*, and

The completely compacted series might then be

As a further illustration, and to show that

tained if trouble is to be avoided in practice. This unity of conception can best be attained by a mathematical consideration of the factors

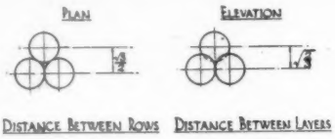

FIG. 7. FIG. 8.

involved, and can be fixed in the mind by a practical demonstration of the mathematical deductions. For the purposes of the following

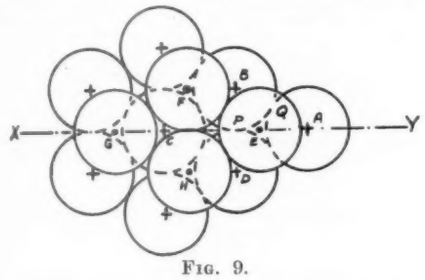

FIG. 9.

calculations it is assumed that the sand grains are spherical.

A superimposed layer of sand does not ordinarily rest on the lower layer, as illustrated in Fig. 1, with one grain immediately over one other grain, or with one grain resting on two grains of the lower layer, as in Fig. 2; but for maximum compaction with unit grains one grain rests on a base of three grains, and over two layers as illustrated in Fig. 3. The foundation layer does not ordinarily arrange itself in a condition illustrated in Fig. 4, but in the condition of close packing (Fig. 5). The mass of sand then tends to arrange itself in a condition of close packing (*c*) on a foundation layer of close packing.

The next most likely condition is open packing on a foundation layer of close packing (*b*), and a further condition is open packing (*a*) on a foundation layer of close packing. It can be shown mathematically that these last two conditions are less compact, and it will be demonstrated later that they do not exist in a sand mass composed of a mixture of grain sizes.

To obtain the volume of sand and the volume of voids in a perfectly compacted sand consisting of spherical grains of uniform diameter, *i.e.*, in the condition of close packing (*c*):

Take the diameter of each grain as a unit and consider the number of spheres to be packed in a cube of side a units long (Fig. 6): then a row of spheres along one edge will contain a spheres. The distance perpendicular to the side of the cube between one row and the next will be $\frac{\sqrt{3}}{2}$ (Fig. 7) and the number of rows will be $\frac{2a}{\sqrt{3}}$ and the number of spheres in a layer will be $\frac{2a^2}{\sqrt{3}}$.

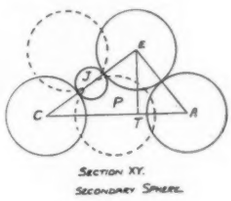

FIG. 10.

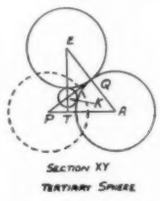

FIG. 11.

The perpendicular distance from one layer to the next is $\sqrt{\frac{2}{3}}$ units (Fig. 8) and the number of layers is $\frac{a\sqrt{3}}{\sqrt{2}}$.

Then the total number of spheres is $\frac{2a^2}{\sqrt{3}} \cdot \frac{a\sqrt{3}}{\sqrt{2}} = \sqrt{2}\,a^3$.

This is only true where a is large, which is the case with moulds and cores.

The volume of a sphere is $\frac{4}{3}\pi r^3$; if the diameter is one unit, the volume becomes $\frac{4\pi}{3}\frac{1}{2^3}$ or $\frac{\pi}{6}$.

The total volume of perfectly compacted unit spheres in a cube of a units side is $\sqrt{2}\,a^3$, $\frac{\pi}{6}$ or $\frac{\pi\sqrt{2}}{6}\,a^3$ or $0.74\,a^3$; and since the volume of the cube is a^3, then the volume of the voids is $0.26\,a^3$, *i.e.*, 74 per cent. of the space is occupied by sand and 26 per cent. of the space is *void*.

Similarly for the condition of open packing (*b*) on a foundation layer of close packing, it can be shown that 70 per cent. of the space is occupied by sand and 30 per cent. of the space is void, and for open packing (*a*) on a foundation layer of close packing, the space occupied by sand is 60 per cent., and the void is 40 per cent. The condition of close packing (*c*) is the condition of lowest void content, *i.e.*, 26 per cent. voids.

This is in agreement with H. A. Schwartz in a Paper given to the American Foundrymen's Association, in which he shows that the closest packing of a mass of spheres free to move or rammed into place in a container having dimensions a multiple of their diameters is the tetrahedral.

H. E. White and S. F. Walton in a Paper entitled "Particle Packing and Particle Shape," given in the Journal and Ceramic Abstracts, American Ceramic Society, May, 1937, also give the tetrahedral system as the condition of closest packing.

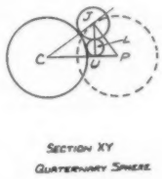

FIG. 12.

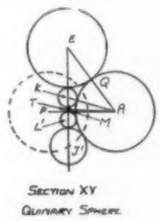

FIG. 13.

Having established this condition of closest packing for grains of unit size, the sizes of rounded grains, which can fit in the voids existing between these unit grains of this tetrahedral arrangement, were calculated and found to be as follows:—

Where d is the diameter of the unit grain,

	No. of grains.
d	1
$0.414d$	1
$0.22d$	2
$0.18d$	8
$0.15d$	7

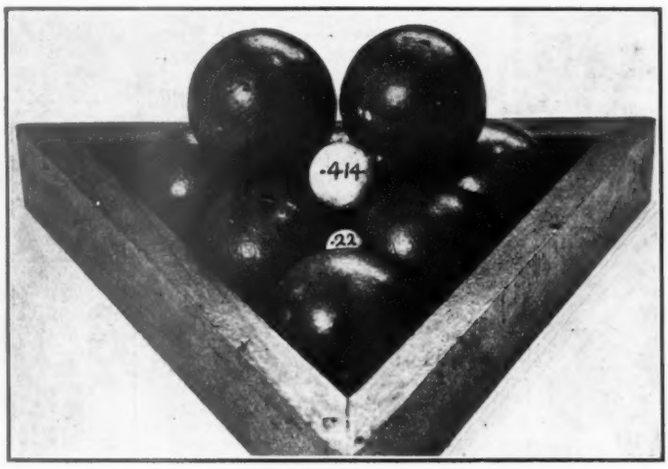

FIG. 14.—"FITTING-IN" ARRANGEMENTS OF THREE SIZES.

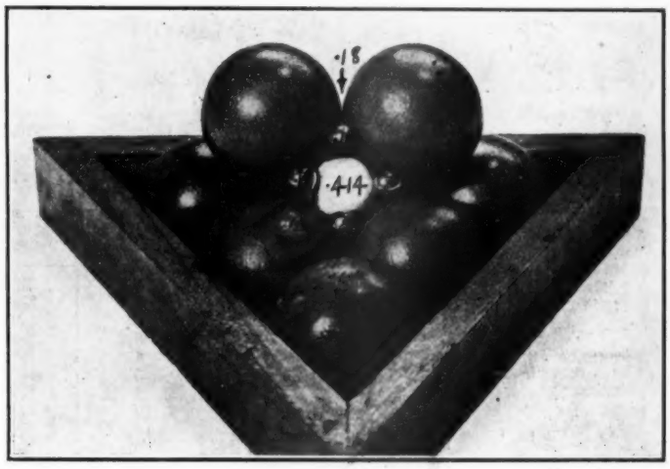

FIG. 15.—A SECOND ARRANGEMENT OF "FITTING-IN."

White and Walton give an alternative to the 0.15 size (it is $0.116d$), and arrange the fitting sizes in the following series:—

	No. of grains.
Primary sphere d	1
Secondary sphere $0.414d$	1
Tertiary sphere $0.225d$	2
Quaternary sphere $0.177d$	8
Quinary sphere $0.15d$ and an alternative $0.116d$	8

Schwartz arranges the fitting-in sizes in two series as follows:—

		No. of grains.
Primary and secondary series	d ..	1
	$0.414d$..	1
	$0.22d$ ..	2
Ternary series ...	d ..	1
	$0.414d$..	1
	$0.22d$ ..	2
	$0.154d$..	7

The tetrahedral arrangement is shown and the sizes represented diagrammatically with letters J, K, L in White and Walton's Paper by Figs. 9, 10, 11 and 12. The alternative to $0.15d$ is shown with letter M (Fig. 13). Figs. 14 and 15 are photographs showing the arrangement of

indicated by this graph, was used to make test- sand consisting of rounded grains of uniform size. The smaller the grain size the larger the

approximately half that of silicon.

chromium, has a very pronounced influence in

J. W. Donaldson. Journal of the Iron and Steel Institute, 1933, Vol. 78, pp. 255-274.

three " fitting-in " sizes—the 0.414*d*, 0.22*d*, and 0.18*d*.

Expressed by weight or volume this compacted tetrahedral series becomes:—

No. of grains.	Diameter.	Wt. or Vol.	Per cent. Wt.
1	*d*	$1.000\frac{\pi d^3}{6}$	74.2
1	0.414*d*	0.071 ,,	5.2
2	0.220*d*	0.021 ,,	1.6
8	0.180*d*	0.047 ,,	3.5
8	0.116*d*	0.012 ,,	0.9
		1.15 ,,	85.4

The total volume of grains is now $1.15\frac{\pi d^3}{6}$.

The total number of *unit* grains in a cube of *a* sides is $\sqrt{2}\ a^3$, and the volume is $\frac{\pi\sqrt{2}\ a^3}{6}$ or $0.74a^3$, and the total volume of the compacted series in a cube of *a* sides is

$$1.15\frac{\pi d^3\sqrt{2}}{6}a^3 \text{ or } 0.854a^3$$

The fitting-in grains have increased the sand content by 11.4 per cent. and decreased the voids from 26 to 14.6 per cent. Although the void content is considerably reduced, there remains 14.6 per cent. to be filled by material in size less than 0.116*d* to infinitely small.

A completely compacted series, which would obviously be absolutely impervious, can then be represented as follows:—

Diameter of grains.	Per cent.	Wt. or Vol. per cent.
d	74.2	
0.414*d*	5.2	
0.22*d*	1.6	85.4
0.18*d*	3.5	
0.116*d*	0.9	
Less than 0.116*d*	—	14.6

or as 0.22*d* and 0.18*d* are almost equal:—

Diameter of grains.	Wt. or Vol. per cent.
d	74.2
0.414*d*	5.2
0.22*d*	5.1
0.116*d* to infinitely small	15.5

This can be approximated to read

Diameter of grains.	Wt. or Vol. per cent.
d	74.2
2/5*d*	5.2
1/5*d*	5.1
1/10*d* to infinitely small	15.5

This constitutes a simple mathematical relationship, easily remembered.

In order to relate these sizes to those actually found in practice, it will be convenient to give here the screens used and the size in inches of the mesh openings.

The screens used in control work are the I.M.M. series, and are as follow:—

	Ins.
+ 10	0.0500
+ 20	0.2500
+ 30	0.0166
+ 40	0.0125
+ 50	0.0100
+ 70	0.0071
+100	0.0050
+150	0.0033
+200	0.0025
−200	<0.0025

If *d* is made equal to the mesh size of the + 30 I.M.M. screens, *i.e.*, to 0.0166 in., 2/5*d* becomes 0.0066 in., *i.e.*, + 75 mesh; 1/5*d* becomes 0.0033 in., *i.e.*, + 150 mesh; 1/10*d* becomes 0.00166 in., *i.e.*, − 200 mesh. (The + 75 mesh is not at present made in the I.M.M. series, and the + 70 is substituted in these considerations.)

The completely compacted series might then be expressed by the weights on the sieves:—

	Ins.	Per cent.
+ 30	0.0166	74.2
+ 70	0.0071	5.2
+150	0.0033	5.1
Pan material	0.00166	15.5

or arranged in columns as follows:—

d	2/5*d*	1/5*d*	1/10*d*
+ 30	+ 70	+150	Pan material

and extended to include other mesh sizes:—

d	2/5*d*	1/5*d*	1/10*d*
+ 30	+ 70	+150	Pan material
+ 40	+100	+200	Pan material
+ 50	+150	−200	Pan material

This completely compacted series

Unit	2/5 Unit	1/5 Unit	1/10 Unit
+ 30	+ 70	+150	Pan material
74.2 per cent.	5.2 per cent.	5.2 per cent.	15.5 per cent.

would give imperviousness and maximum density provided the pan material contained all sizes from 0.00166 in. dia. to infinitely small.

It is most important to consider, however, that the exact positioning of each grain according to the diagram illustrated is impossible to attain in practice, but it is possible to know exactly what grain sizes are most effective in controlling permeability and density.

A few experiments will illustrate this. To show that fitting-in does take place, a series of test-pieces was made by ramming together a mixture of two sands.

	Per cent.		Per cent. 100 for comparison.
(I)		+ 20	90
(II) + 30	10	+ 20	90
(III) + 40	10	+ 20	90
(IV) + 50	10	+ 20	90
(V) + 70	10	+ 20	90
(VI) +100	10	+ 20	90

The lengths of the test-pieces in inches were then accurately measured:—

Number of blows.	(I)	(II)	(III)	(IV)	(V)	(VI)
0	2.180	2.180	2.170	2.050	2.082	2.110
1	2.032	2.030	2.000	1.950	1.966	1.928
2	1.994	2.004	1.968	1.930	1.936	1.898
3	1.978	1.990	1.950	1.912	1.916	1.880
4	1.964	1.980	1.942	1.900	1.902	1.880
5	1.954	1.966	1.928	1.892	1.892	1.870
7	1.940	1.950	1.912	1.878	1.878	1.860
10	1.926	1.936	1.894	1.860	1.860	1.828
15	1.906	1.910	1.872	1.844	1.840	1.808
25	1.880	1.884	1.848	1.822	1.814	1.784
50	1.846	1.850	1.812	1.786	1.778	1.752

The percentage decrease obtained after 50 blows was—

	Per cent. decrease.
I.—+ 30	0.2
II.—+ 40	1.8
III.—+ 50	3.25
IV.—+ 70	3.70
V.—+100	5.10

No decrease occurs with the + 30 size, but a slight decrease occurs with the + 40, due to the + 20 containing all sizes from − 10 to + 20, *i.e.*, from 0.0499 in. to 0.0250 in. The first substantial decrease occurs with the + 50, *i.e.*, with the size 2/5 of the + 20.

A better illustration of the fact that fitting-in does take place is produced by using a larger quantity of a fitting-in size. Once again + 20 and + 100 mesh were used, and 50 per cent. of both sizes were used to make the test-pieces. One test-piece was made by placing a layer of the + 20 on a layer of + 100, and the other test-piece was made by intimately mixing the + 20 and + 100 (see table at head of next column).

The decrease in length when the sands were intimately mixed was 12 per cent., and is illustrated graphically in Fig. 16. The permeability was reduced by more than 60 per cent.

As a further illustration, and to show that a mixture of sand grains does arrange itself in the condition of close packing (*c*), *i.e.*, the tetrahedral system, the lengths of test-pieces

No. of blows.	Sand in layers. Length of test-piece.	Sand mixed. Length of test-piece.
0	2.094	1.858
1	2.020	1.774
7	1.950	1.716
25	1.886	1.678
50	1.856	—
Permeability after 7 blows	210	80

obtained by ramming mixtures of + 40 mesh and + 70 mesh in proportions from 100 per cent. of one to 100 per cent. of the other were measured. No fitting-in occurs. If the + 40 sand was in

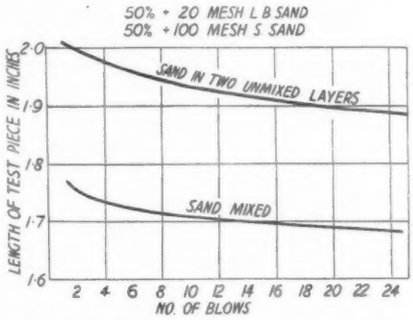

FIG. 16.—INFLUENCE OF MIXING ON LENGTH OF TEST-PIECE.

the condition of open packing (*a*), *i.e.*, the cubic system, the largest size of sand grain capable of fitting-in would be 0.732 times the diameter of the + 40 or 0.00915 in.; then the + 70 with a diameter of 0.0071 in. would readily fit-in, producing a decrease in the length of the test-piece.

The graph in Fig. 17 shows a maximum reduction of 3 per cent. in the length of the test-piece when increasing percentages of + 70 are mixed with + 40. This slight reduction in length of the test-piece is accounted for by the fact that it is practically impossible to sieve the + 70 grains free from small quantities of − 70 grains which would fit into the − 30 + 40 grains; and also the accuracy of standard sieves cannot be relied upon within very fine limits. This figure also indicates that the reduction in permeability is less than that obtained by mixing sands that have a greater difference in grain size.

Further work done in association with Mr. Parkes, of the British Cast Iron Research Association, some of which has been reproduced in Research Report No. 138 (January, 1938), also confirms and illustrates this assumption.

Fig. 18 graphically represents the length of test-piece and the permeability numbers obtained with mixtures of + 20 and + 100 mesh sand, showing fitting-in and reduction in permeability obtained. Fig. 19 is a graph showing the fitting-in obtained with two sands from the Leighton Buzzard deposits actually in use in the core shop. The mixture giving maximum density,

is large, for example, 40 mm., it is found that the material of the mould are carried along and satisfy

indicated by this graph, was used to make test-piece III in Fig. 24.

With this conception of a simple relationship between the grain sizes,

$$d, \quad \frac{2d}{5}, \frac{1d}{5}, \text{ and } \frac{1\,d}{10}$$

the control of permeability becomes more certain, and the relationship between permeability requirements and other required qualities in a core, sand consisting of rounded grains of uniform size would give good permeability with good finish, but unfortunately there are many disabilities accompanying the use of such a sand. These disabilities can be overcome by the use of a mixture of grain sizes, maintaining at the same time good permeability and good finish on the castings and other requirements of a good core and good core-shop practice.

Using fine sand alone increases the amount of binder required. In unit quantity of sand, the number of grains is inversely proportional to the cube of the diameter, *i.e.*, $1/(\text{diameter})^3$. The surface area of each grain is proportional to $(\text{diameter})^2$. Therefore, the total surface area in unit quantity is directly proportional to the number of grains, or the resultant increase in total surface area is inversely proportional to the size. The smaller the grain size the larger the surface area.

Then + 70 sand should require 2½ times the amount of binder required by a + 30 sand. The amount however is a little less than this, as the strength of the core is influenced also by the number of points of contact between the grains. For economy in binder, it is essential, therefore, to use as large a grain size, or as large a proportion of large-grained sand, in the mix as is possible. Where good finish on the surface of the casting is the main consideration, small-grained sand is again obviously the choice, and for good permeability these grains should be uniform in size.

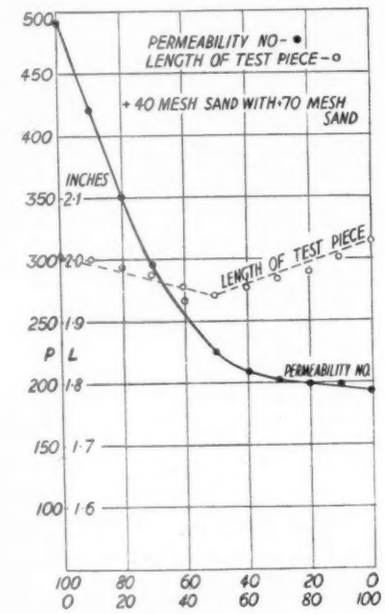

FIG. 17.—TEST-PIECE LENGTH AND PERMEABILITY CORRELATED WITH SAND MIXES.

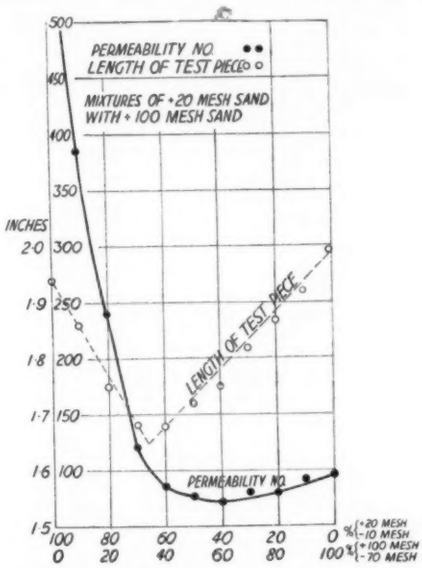

FIG. 18.—INFLUENCE OF MIXING ON LENGTH OF TEST-PIECE AND PERMEABILITY.

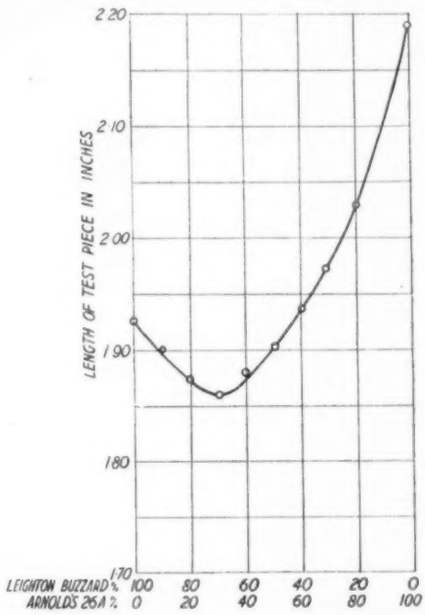

FIG. 19.—INFLUENCE OF MIXING ON LENGTH OF TEST-PIECE.

more obvious. Core mixtures currently used for some obscure or forgotten reason were re-examined in the light of this relationship, and many of the mixtures were eliminated, and those retained were improved.

Previously it has been mentioned that a fine

(*To be concluded.*)

GATING WITH SPECIAL REFERENCE TO THE OPTIMUM FLOW CONDITIONS IN THE MOLTEN METAL

By Dr. E. M. H. LIPS*

[*Presented on behalf of the Nederlandsche Vereeniging van Gieterij-Technici*]

The importance of the question concerning the manner in which the molten metal should be fed to a mould is too well known to every practical foundryman to require discussion here. It may therefore be regarded as characteristic that during the past few years attempts have been made to investigate more fundamentally the processes which take place during the filling of moulds and thus to break away from the previous custom of describing the effects produced on the quality of the casting by interfering with foundry practice.

It is now recognised that the application of important conclusions made in related subjects will generally ensure a satisfactory result. It is also an obvious step to apply the laws of flow dynamics in the foundry where liquid metal is handled, especially since the importance of flow dynamics was first proved in hydraulics and later in aeroplane design. The application of the principles of flow dynamics at a relatively late date in foundry practice may be explained as being due to the fact that through the use of moulding boxes the flow of the metal through the mould is not visible to the eye, so that it is more or less impossible to observe the phenomena which occur during pouring. The present Paper is intended to draw attention to some laws of flow which are important for foundry practice and which permit general rules to be established for the design of casting gates.

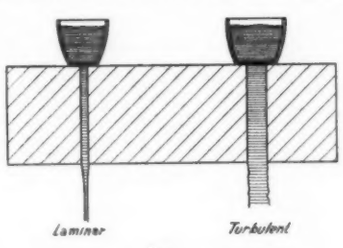

FIG. 1.—SMALL AND LARGE DIAMETER RUNNERS GIVING LAMINAR AND TURBULENT FLOW RESPECTIVELY.

For the purpose of considering the process of pouring metal into a mould, the latter may be subdivided into three parts:—

(1) All the channels through which the molten metal has to pass before entering the mould proper.

(2) The mould proper.

(3) The channels provided for the purpose of obviating the effects of cooling phenomena, such as the formation of cavities, after the mould has been filled with the molten metal.

It is clear that the channels mentioned under (1) have primarily to satisfy hydrodynamical requirements, while the channels mentioned under (3) have nothing to do with the flow of the molten metal, but are only operative after the molten metal has come to rest.

Consideration therefore will be confined almost exclusively to the channels mentioned under (1). Fig. 1 shows two runners on top of which is placed a pouring bush. If the bush is filled, for example, with molten iron and the stopper is removed, the iron will flow through the runner into any cavity located beneath. If the diameter of the runner in the case of one mould is small, for example, 4 mm., and in the case of the other

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is large, for example, 40 mm., it is found that the nature of the flow from the exit is very different in the two cases.

The molten metal issues from the runner of larger diameter in the form of a very turbulent and unsteady flow, while a very steady and smooth-exit flow occurs in the case of the runner with the smaller diameter. The metal flowing through the runner of large diameter produces considerable frothing in any receptacle situated beneath it, while the same metal flowing through

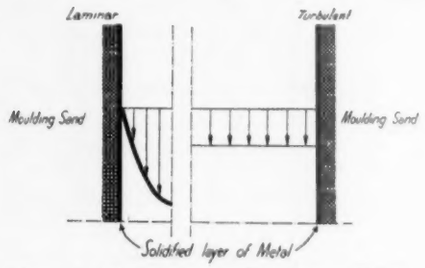

FIG. 2.—LAMINAR AND TURBULENT FLOW THROUGH RUNNERS.

the channel of small diameter causes practically no frothing. In the case of molten aluminium, this difference is, if possible, even more pronounced.

The differences outlined above may be fully explained by reference to Fig. 2. The flow of the metal through a channel or runner of small diameter is laminar or streamline, that is to say, the mean velocity of the flowing metal is a maximum in the centre and approaches zero at the wall of the channel. The curve showing the distribution of the velocity is a parabola. The flow of the metal passing through the runner of large diameter is, on the contrary, turbulent, that is to say, the mean velocity of the flowing metal is almost constant throughout the entire cross-section of the channel.

If a particle moving in laminar flow be considered, its path is found to be rectilinear. In the case of a particle moving in turbulent flow, on the contrary, its motion takes place along wholly irregular and curved paths. If the flow of metal through a pouring gate is streamline, the thin film solidifying on the wall of the gate

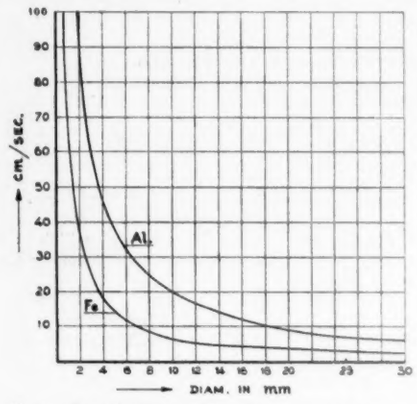

FIG. 3.—CRITICAL VELOCITY RELATED TO DIAMETER OF RUNNER FOR IRON AND ALUMINIUM.

will remain intact, because the velocity of the flowing metal is practically zero along the wall. The sand of the mould is thus protected by a film of solidified metal.

In the case of turbulent flow, a film of solidified metal will likewise be formed, but will be partly detached by the metal flowing along it at a considerable velocity and will take particles of sand along with it. With turbulent flow, a slight suction is also produced in places, in consequence of which gases present in the material of the mould are carried along and contaminate the metal. It is clear that this will result in the formation of dirt which can practically no longer be removed. This may be expressed as follows:—Laminar or streamline flow prevents the formation of dirt, while turbulent flow promotes such formation.

The question which now arises is, therefore: how can laminar flow be attained or at least approached more closely? The nature of the

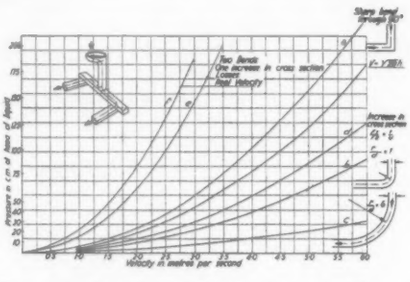

FIG. 4.—VARIATION OF VELOCITY OF METAL THROUGH THE POURING GATE WITH PRESSURE.

flow of any fluid through a channel or pipe depends directly upon the velocity V_o [m.sec.$^{-1}$], the pipe diameter d [m.] and the kinematic viscosity ν (nu) [m^2.sec.$^{-1}$]

$$R = V_o \frac{d}{\nu} \quad . \quad . \quad . \quad . \quad . \quad (1).$$

For smooth runner or "pipe" walls, flow is only laminar when $R \leq 2{,}500$. For greater values of R, the flow is turbulent. It will be seen that V_o and d denote values depending upon the dimensions of the mould, while ν is a constant of the material. Assuming for cast iron a viscosity of 200 . 10^{-6} [kg.sec.m.$^{-2}$], then

$$\nu = \frac{200 \,.\, 10^{-6}}{715} = 0.28 \,.\, 10^{-6} \text{ [m}^2\text{.sec.}^{-1}\text{]} \quad . \quad (2).$$

Taking the limit value of R as 2,500, it is possible to calculate, for example, for a given pipe diameter, the permissible velocity of the liquid which just produces laminar flow. This velocity is also called the critical velocity. The curve in Fig. 3 shows these relationships. Although the viscosity of aluminium is not yet known, a curve has also been given for this metal on the assumption that the viscosity is approximately the same as that of iron. The fundamentally more satisfactory behaviour of light metals with regard to running power may be gathered from these curves.

It can furthermore be deduced from Fig. 3 that the diameter of the pouring gate must be

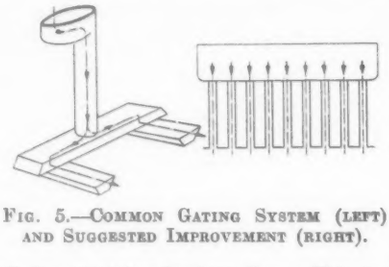

FIG. 5.—COMMON GATING SYSTEM (LEFT) AND SUGGESTED IMPROVEMENT (RIGHT).

small for attaining laminar flow. This is the chief reason why a pouring gate should not be combined with a riser. For well-known reasons, risers must always be of large diameter.

It may also be said that the pouring gate must be designed on purely hydrodynamical principles, while the design of the riser is governed by the crystallisation properties of the cast material when at rest. The importance of the hydrodynamical design of the gating system will also be apparent from the following requirements which a good gating system should satisfy, for a small pouring gate diameter is not everything.

Fig. 4 shows the variation of the velocity of the metal flowing through the pouring gate with the pressure. Curves *a*, *b* and *c* show the loss of pressure, relative to the velocity of the liquid, which occurs when the molten metal undergoes a change in direction of 90 deg.

These curves were constructed on the following basis: If the resistance which the change in

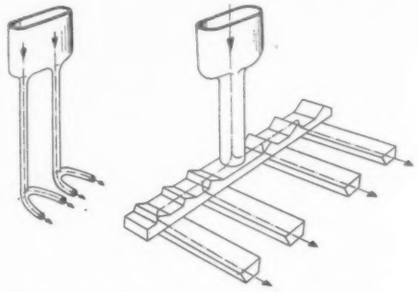

FIG. 6.—GATING SYSTEM WITH DIRT TRAPS (RIGHT) AND AN IMPROVED SYSTEM (LEFT).

direction offers to the flow is equal to ζ (zeta), then

$$\zeta = \frac{\Delta p}{V_o^2 \,.\, \frac{\rho}{2}}$$

where Δp [kg. m.$^{-2}$] = loss in pressure caused by the change in direction.

V_o [m. sec.$^{-1}$] = velocity of the flowing liquid.

ρ [kg. sec.^{2} m.$^{-4}$] = specific gravity.

For a sharp bend of 90 deg. with a rough surface, Kirchbach and Schubert found a value of 1.27 by measurement. For a bend with a radius of curvature equal to the diameter of the pipe (curve *b*), this value is 0.50. For a radius of curvature equal to six times the diameter of the pipe (curve *c*) the value is 0.18. Although it should be definitely stated that these figures are not applicable to the flow of molten metal through a much cooler pouring gate, it is permissible to employ the value *n* for purposes of comparison, especially since the comparisons developed in hydrodynamics are also substantially applicable to liquids such as molten metal, while no values are yet known in the literature for

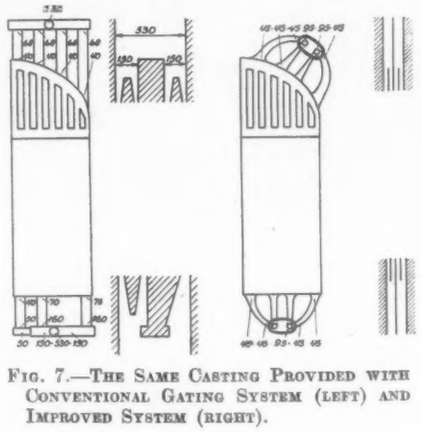

FIG. 7.—THE SAME CASTING PROVIDED WITH CONVENTIONAL GATING SYSTEM (LEFT) AND IMPROVED SYSTEM (RIGHT).

correcting the above-mentioned numerical values.

It will be gathered from Fig. 4 that, for example, at a velocity of 3 metres (9.8 ft.) per second, the loss in pressure head for a sharp bend (curve *a*) is about 60 cms. (24 in.). For a curvature such as that given by the curves *b* and *c*, this loss is reduced to 20 cms. (8 in.) and 8 cms. (3 in.) respectively. This clearly shows the significance of the gate known as the horn gate.

It is necessary to avoid not only a sudden change in direction of the flowing metal, but also abrupt changes in the cross-section of the gate, the loss in the case of a sudden increase in cross-section being particularly noticeable. Curve *d* shows the loss for a sudden increase in cross-section of one-quarter. The curve was plotted for a value of ζ of 0.7. Of course, the restricting condition mentioned above also applies in this case. Assuming now that there are two sudden changes in direction and a sudden increase in cross-section in a gating system (the example indicated in Fig. 4 shows the possibility of this condition), the losses may then be represented by the curve *e* and the actual velocity by the curve *f*. In the example cited, for a gate 100 cms. (40 in.) in height, for instance, the theoretical velocity as calculated from the equation $V = \sqrt{2gh}$ would be about 4.5 m. per sec. (18 ft. per sec.), while the actual velocity is only 2.2 m. per sec. (7.5 ft. per sec.), giving a factor of usefulness of about 50 per cent. Compared with corresponding data in the literature, this figure appears quite possible.

Practical Examples

It will now be of interest to illustrate the application of the above theory with reference to some examples. The left-hand portion of Fig. 5 shows a gating system which is in common use. It will be seen that not only is there a repeated change in direction, but there are also sudden changes in cross-section. In the right-hand portion of Fig. 5, the single pouring gate has been replaced by a large number of thin gates. Changes in cross-section and direction are avoided as much as possible, while the gate diameter is also very small. The satisfactory effect of "pencil gates" employed in some quarters may thus be explained.

The right-hand portion of Fig. 6 shows a gating system provided with what are called "dirt traps." From the foregoing, it will be clear that the writer is not an advocate of such dirt traps, which merely set up resistance and turbulence. This system can be very successfully replaced by the arrangement shown on the left in Fig. 6, which corresponds better to satisfactory flow conditions.

Fig. 7 shows two diagrams of the same casting. On the left, it is provided with the usual gating system, and on the right with a system of new design. The numerical values shown in the figure indicate the cross-sections of the various channels in square millimetres. The small diagram shows the variation in cross-section. Comparison of the two gating systems will clearly show that not only have sudden changes in direction been avoided as much as possible, but also sudden variations in cross-section, thus resulting not only in an improvement in the quality of the casting, but also in a considerable reduction in the weight of the gates and runners.

SOME IRON CASTINGS FOR STEELWORKS PLANT

By JOHN ROXBURGH*

Introduction

Machin and Oldham in a Paper† entitled "Castings," presented some years ago before this Institute, made the following statement:—"So many variables are associated with the manufacture of castings that the degree of success depends mainly on the decisions made by those responsible for the methods of procedure."

That statement, although brief, contains a wealth of truth. If one proceeded to amplify it in detail, one would be confronted with a tremendous task. A story would have to be unfolded, crammed full of experiences, containing descriptions of successful and unsuccessful experiments and endeavour, and detailing the various data collected, in order to lead up to the main theme, that of success depending on decision.

Year by year, the responsibility attached to the foundry executive becomes more and more important and, indeed, more exacting. It must be acknowledged that tremendous strides have been made in foundry practice during the past twenty years, mainly technical and metallurgical, and this progress has made possible the improved standard and wider application of the products emanating from the foundry. At the same time, however, the skilled operative must continue to play his part, particularly where the human element is all-important, and his contribution to the finished article must receive due recognition. Decisions respecting all phases of manufacture having been made by the responsible officials, organisation effected, technical and practical details considered, suitable tackle and materials provided—undoubtedly the chief considerations as they are—yet, without the skill and co-operation of the operative, their schemes, plans and ideas would fail. Happy is the foundry executive who has skilled men upon whom he can depend to follow his instructions.

It is obvious, then, that a combination of practice and technique, in which latter undoubtedly the greatest progress has been and is being made, is necessary to ensure the production of a satisfactory casting, and a casting can only be termed satisfactory after it has passed through the stages of manufacture, has fulfilled all the required tests, been submitted to inspection, finally to give a reasonable service life, according to some considered standard of the user. Thus the foundry executive must, before the commencement of manufacture, be aware of the precise service conditions demanded. At the same time he must produce a sound casting in every sense of the term, and one of good appearance, true to shape and size, to say nothing of the economic aspect of production.

After having given the necessary consideration to all the practical details, he must, of necessity, place great importance on the metallurgical aspect. He knows that, until recent years, the analysis of a casting appears to have been the chief consideration, although he has been aware, from his experience, that two irons of the same composition can give very widely differing physical properties. He has also learnt that, in the main, properties of cast iron can be attributed to the quantity and condition of the graphite, and that by the latter's refinement, dispersion and reduction in amount, great improvements can be effected. Recently, therefore, in his deliberations regarding the most suitable metal for some particular casting, it has become essential for him first and foremost to decide the ultimate structure he desires, and, in contemplating the manufacture of any high-grade casting or one to withstand special service conditions, his first thought has had to be the attainment of a suitable structure in the metal of the casting. In order to obtain such a structure, the analysis of the metal is naturally a good guide, as, for instance, a low total carbon will help first of all in the refinement and quantity

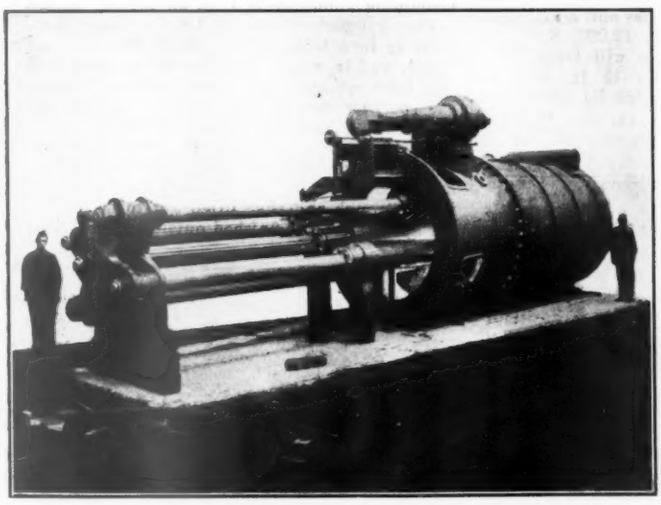

FIG. 1.—HYDRAULIC INTENSIFIER FOR PRESS.

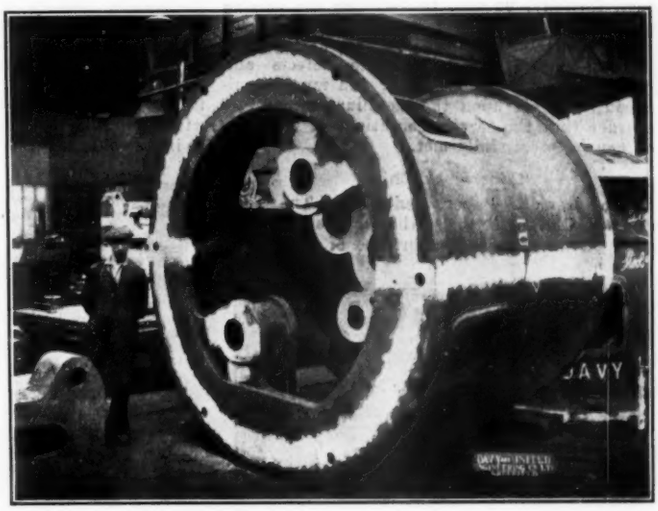

FIG. 2.—A 27-TON STOOL CASTING.

* Foundry manager, Davy and United Engineering Company, Limited, Park Iron Works, Sheffield.

† W. Machin and M. C. Oldham, "Castings." Proc. I.B.F., 1934-5, Vol. 28.

of graphite. The materials comprising the mixture, steel mixtures, the addition of alloys, the furnace in which the melting is carried out, the amount of superheat, the inoculation of the metal by some well-known process, artificial means of accelerating or prolonging the cooling rate, heat-treatment—these all have their effects on the ultimate structure to be found in a cast-

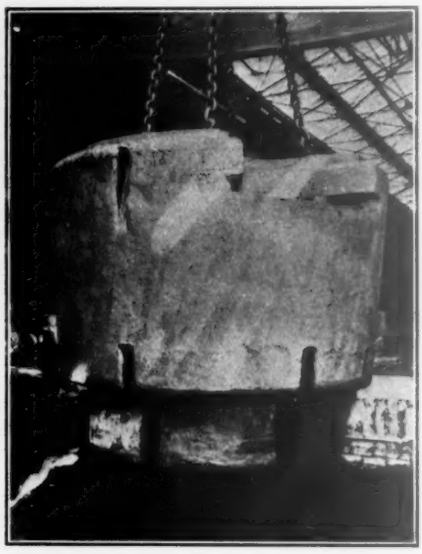

FIG. 3.—MAIN CORE FOR STOOL CASTING.

ing, and on the physical properties of the resultant metal. Thus the foundry executive must, initially, be able to visualise the casting to be produced, so that he can determine his practical methods of procedure and, at the same time, be aware of the possible defects and troubles he must try to avoid, and must simultaneously decide upon the metallurgical aspects in order that the service conditions of the casting can be successfully met.

Control by Chills

In a previous Paper,* entitled "The Technique of Chilling," the author makes reference, based on his personal experience of roll manu-

FIG. 4.—FINISHED OUTSIDE MOULD FOR STOOL CASTING.

facture, to the use of a chill test as applied to grey iron castings as apart from actual chilled castings. For all his special mixtures of iron, the author continues to make use of a chill test-piece 6 in. by 6 in. by 1½ in., which has proved very helpful in practice.

Great attention is paid, naturally, to the selection of materials used for all metal mixtures, and the scrap resulting from such is kept apart. Variation, however, is bound to creep in due to the use of such scrap, as it can only be given a general term, *e.g.*, cylinder scrap, and its structure and composition may differ slightly. Conditions of melting in the cupola, too, may vary from day to day.

With similar mixtures of iron, in attempting to obtain suitable structures, a chill test readily indicates, before casting, any great irregularities in the foregoing and gives the executive, by viewing the test-piece before casting, the opportunity of deciding whether the metal is satisfactory or not for the particular job.

By experience, data can be collected of metal mixtures used, compositions and structures obtained and the depth of chill on the test-piece correlated with the weight and section of the casting, the machinability, physical and pressure tests. A cylinder metal analysing, for instance, 2.9 T.C; 0.8 Si; 0.5 Mn; 0.12 S; and 0.2 per cent. P would probably show 1½ in. depth of chill on a test-piece, whilst a similar mixture but with higher silicon, say 1 per cent., would give approximately 1-in. chill.

With alloy irons containing hardening elements, *e.g.*, chromium, a limit for depth of chill on a test-piece can be determined to permit ease of machining. The test is viewed before casting, and, if above this limit, ferro-silicon may be added to soften the iron, to bring the casting within the bounds of machinability.

The engineering company with which the author is associated enjoys a high reputation for rolling mills and forging presses, and so the author is called upon to make castings for these, in addition to other steelworks plant. He hopes, as fully as possible in the space available, to describe the manufacture of certain of these typical castings.

Forging and Bending Presses

At the present moment his company is well forward with the manufacture of two of the largest presses ever made in England. The presses comprise a 15,000-ton bending press and a high-speed forging press to operate at 12,000, 8,000 and 4,750 tons. The latter press will forge hollow drums up to 18 ft. dia. by 19 ft. long and is served by four steam hydraulic intensifiers, with hydraulic cylinders, 95 in. dia. by 10 ft. 4 in. stroke, with steam pressure of 150 lbs.

FIG. 5.—INTENSIFIER CYLINDER CASTING.

per sq. in. and hydraulic pressure of 3 tons per sq. in. in the main press cylinder.

The total weight of the 12,000-ton forging press, including valves and intensifiers, but no other auxiliaries, is approximately 3,000 tons, whilst the total weight of the four intensifiers approximates 400 tons. Incidentally some of the steel castings required for these two presses weigh 120 tons each when finished and have actually been made in Sheffield.

Intensifier Castings

In the first batch of examples, reference will be made to some of the iron castings made for the above presses. Fig. 1 is a view of one of the four intensifiers, completely erected, showing the stool, the cylinder and cover—inside of which, of course, is the piston body and junk ring, together with the valves and other accessories.

The stool casting is approximately 10 ft. dia. and 8 ft. deep, weighing 27 tons, and Fig. 2 well illustrates its size and intricacy. Loam boards are provided for both mould and main

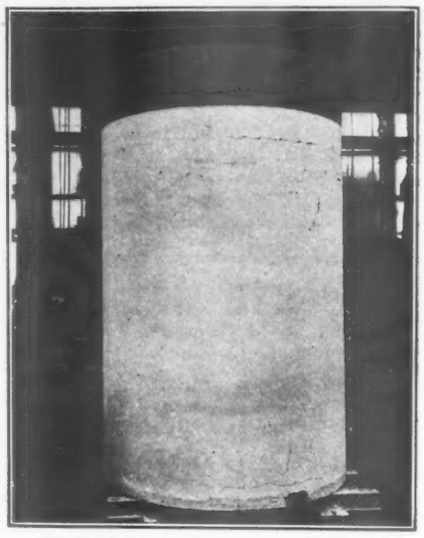

FIG. 6.—CENTRE CORE FOR INTENSIFIER CYLINDER.

core, together with the loose pieces for the branches, windows and internal bosses. The machining allowance is 1 in. on the top flange.

Fig. 3 depicts the finished main core. This is built-up in a trough, which had been previously swept, and in which the internal bosses and ribs had been set accurately. Grids were placed in the pockets formed between the bosses and rammed up, and these were bolted to a main grid, the core then being bricked to the top, with further binders built in, and the top bosses and brackets were located. The core was dried in the trough and then lifted out to be finished.

Fig. 4 shows the finished outside mould, which

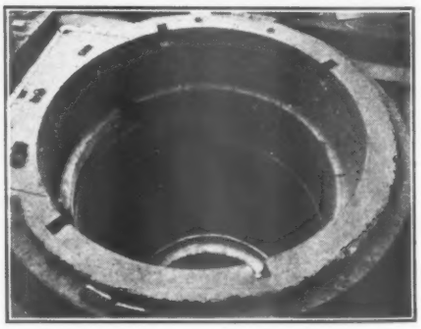

FIG. 7.—MOULD FOR INTENSIFIER CYLINDER.

calls for no explanatory remarks except that it is split at the bottom flange. The segment cores are first bolted down in the bottom, then the branch cores located, and next the main centre core is placed on cast-iron screwed studs, and finally the top plate is added. Incidentally, between the bottom and top plate all cores are packed iron to iron to avoid any movement. The method of running adopted is by using two ladles on opposite sides. On one side are three downgates, 2½ in. dia., two of which enter tangentially on the bottom flange. The metal flows through 16 holes in the segment cores, two in each, as shown, in order to fill the centre of

* J. Roxburgh, "Technique of Chilling." Proc. I.B.F., 1934-5, Vol. 28, pp. 586-603.

the mould. The third downgate is released when the metal is judged to have covered the segment cores. On the opposite side, three top gates, 1½ in. dia., are opened when the mould is three-quarters filled. A casting such as this is apt to crack at the windows and to obviate this possibility, two matters require attention:—(1) A flash is carried across each window; and (2) the mixture of metal is arranged accordingly. liberated, for top running ensured the cleanliness desired. For high-pressure cylinders, a phosphorus content of 0.2 per cent. is usually aimed at, but for low-pressure work this may with safety be raised to 0.4 per cent.

The average analysis obtained from the four cylinders made was:—T.C, 3.22; Si, 1.20; Mn, 0.65; S, 0.090; and P, 0.40 per cent.; but, in this case, no steel was used in the mixture, when closing, the lightening cores were placed on wooden thickness pieces in the mould and then bolted up to the top plate through the 8-in. dia. cores shown, advantage also being taken of these latter cores in order to take off the vent. In this way, all studs on the important bottom machined face were eliminated. A very similar analysis was obtained as for the large cylinders previously mentioned.

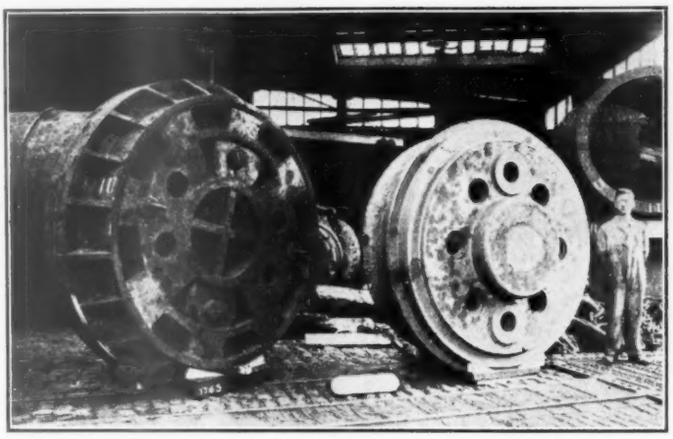

FIG. 8.—CYLINDER COVER AND PISTON BODY.

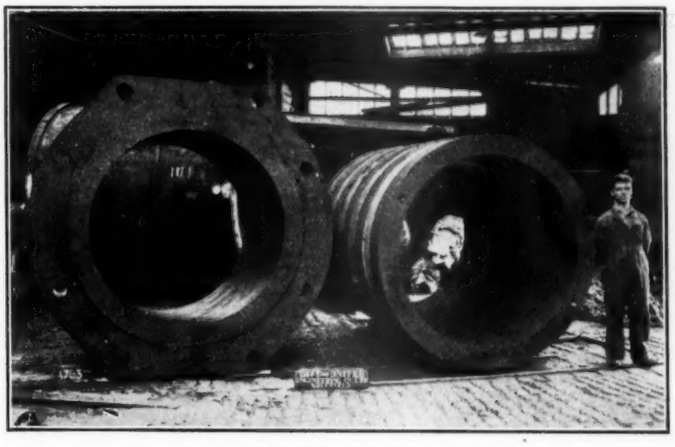

FIG. 9.—GUIDE CYLINDER AND BUSH.

A steel-mix iron, containing a percentage of hematite, was used, and the average analysis of the four castings made was:—T.C, 3.19; Si, 1.27; Mn, 0.64; S, 0.096; and P, 0.40 per cent.

Intensifier Cylinder Casting

The intensifier cylinder shown in Fig. 5 is 95 in. dia. in the bore and 10 ft. 4 in. long, and it is necessary to incorporate 2 ft. of head on the top flange to ensure soundness, the total weight of the casting being 35½ tons. The machining allowance was ⅝ in. in the bore, the average section of metal being 5 in. This which consisted of 30 per cent. mottled iron, 10 per cent. hematite containing 1 to 1.25 per cent. silicon and 1 per cent. manganese, 20 per cent. cylinder iron, 25 per cent. cylinder scrap and 15 per cent. machinery scrap.

Cylinder Cover and Piston Body

Both the cylinder cover and piston body are shown in Fig. 8. The cylinder cover on the left weighs 11½ tons, and was struck up in loam. The outside is lifted off, carried by a joint plate, whilst the top side of the casting, which is shown, is lightened out by cores bolted in prints

Guide Cylinder and Bush

Fig. 9 illustrates two large castings which present probably more of a metallurgical problem from the point of view of soundness and suitable structure, than one of moulding, due to their unusual thickness of metal. The casting on the left is a guide cylinder; it weighs 16 tons, has a 5 ft. 3 in. dia. bore and is 5 ft. long with a head 1 ft. 6 in. long, whilst the metal round the bore is 7 in. thick. The flange cast at the bottom is 10 in. thick as finished. This casting was run with two 2½ in. dia. downgates entering in the bottom flange and seven top gates 2½ in. by

FIG. 10.—HALF-BUSHES FOR PRESS COLUMN.

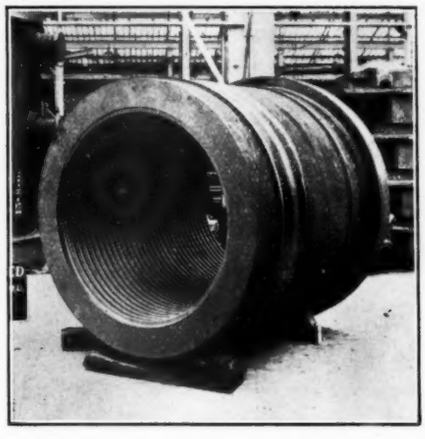

FIG. 11.—COLUMN NUT IN WHICH THE THREAD IS MACHINED FROM THE SOLID.

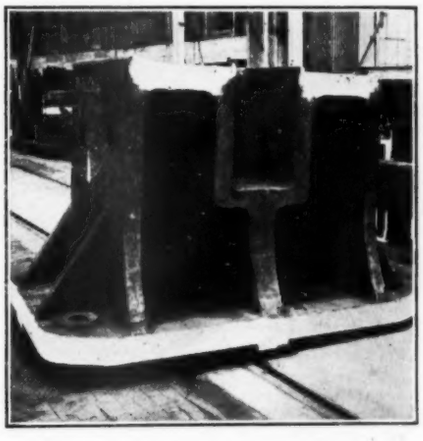

FIG. 12.—SLABBING STOOL CASTING.

casting again is a loam job, boards being provided together with loose branch and bosses.

The centre core (Fig. 6) is built up on a core plate, binders being inserted every 18 in., and the core is finally bolted top to bottom. The outside, shown in Fig. 7, is built up in rings, 2 in. thick, and a drawback made above the branch in order to insert the branch core. The method of running employed was as follows. Two ladles were used to fill the runner dish, when two 2½ in. dia. downgates were released first, which entered tangentially the bottom flange. When about 6 tons had entered the mould, to form a cushion and avoid splashing, fourteen top gates, 2½ in. by ⅞ in., were on the top plate. One inch machining is allowed on the top surfaces of the casting to ensure cleanliness. A combination of top and bottom pouring was again employed, one downgate 2½ in. dia. entering first tangentially in the bottom; later, at a predetermined time, three top gates 1½ in. dia. were released from the top. A cylinder mixture was used, giving as an average analysis for the four castings made:—T.C, 3.25; Si, 1.30; Mn, 0.63; S, 0.092; and P, 0.40 per cent.

The piston body, on the right, weighs 12¾ tons, and a ring head, 1 ft. deep, was incorporated to ensure soundness. This is also a loam job, and, ⅞ in. were released when the bottom flange was completely filled.

The right-hand casting is a bush, weight 23 tons, 5 ft. 3 in. dia. bore by 8 ft. long, with 2 ft. of head and an average thickness of 6½ in. One 2½ in. dia. downgate was employed for running, and after 4 tons of metal had entered the mould, eight top gates 2½ in. by ⅞ in. were liberated.

For both these castings a steel mix was used containing steel, mottled iron, cylinder iron, cold-blast, cylinder scrap and machinery scrap, and analysing as follows:—

Bush.—T.C, 3.04; Si, 1.12; Mn, 0.60; S, 0.122, and P 0.42 per cent.

Guide Cylinder.—T.C, 3.17; Si, 1.08; Mn, 0.54; S, 0.119, and P 0.41 per cent.

Half-Bushes for Press Columns

The half-bushes (Fig. 10) for the press columns weigh 2½ tons each and, in this case, as there were sixteen to make, a full half-pattern was provided. The bottom flange was loose, rammed up separately, and turned over to receive the top part of the pattern, which was dowelled on. A joint was made above the bottom flange and a joint plate used to lift off the mould above this flange. The bore was formed by a core. A head 15 in. high was incorporated on the casting, and the job was cast open, five top gates 1 in. dia. alone being used to fill the mould. A low-carbon, low-silicon, low-phosphorus iron was again used to ensure a close-grained material.

Column Nut

The column nut (Fig. 11), of which four have been made, has a finished weight of 5 tons. It is a particularly interesting casting, as a heavy duty is demanded of it and a tensile strength of at least 16 tons per sq. in. for the material was required. The mould and core were struck up in loam, with 2 ft. head on the top end of the casting, and the bore was cast plain, the deep thread being subsequently machined out of the solid. A combination of top and bottom running was employed, six gates being dropped from the top. A steel-mix iron was used to give an average analysis of :— T.C, 2.92; Si, 0.98; Mn, 0.54; S, 0.105, and P 0.35 per cent., again emphasising the importance of low contents of carbon, silicon and phosphorus. In the root of the thread, the metal was perfectly sound, close-grained and free from any sponginess.

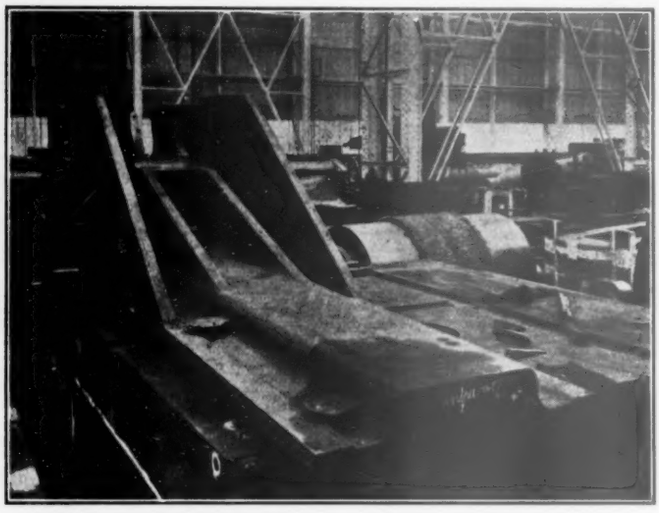

FIG. 13.—OFFSIDE BRACKET WEIGHING 20 TONS.

FIG. 14.—MOULD FOR THE CASTING SHOWN IN FIG. 13.

Slabbing Stool and Offside Bracket

Another press casting, a slabbing stool weighing 16 tons, is shown in Fig. 12. A full pattern, completely blocked, was provided, the job being moulded on its side with two sets of cores, with metal between them. Iron studs and packings were used throughout to counteract any lifting. This casting is bulky, with fairly heavy sections of metal, and in order to withstand service conditions a steel-mix iron was used.

A final example of a press casting, an offside bracket, is illustrated in Fig. 13. It weighed 20 tons, is 20 ft. long and 5 ft. at the deepest part. As the slides on this casting are very important, these surfaces, of necessity, were moulded in the bottom. This naturally increased the difficulties of moulding, and Fig. 14 gives a view of the mould showing the awkward jointing involved. This necessitated a large volume and weight of sand being carried on the top part, grids being used and bolted with strong bolts to the top part. Fig. 15 depicts this feature quite well. Actually, two separate top parts were used in order to facilitate coring up, as will be obvious. The top part carrying the deep cods was placed in position first, and the coring up of the deep end was then carried out, and in this way studs could be placed between the cores and the deep cods of sands to secure the cores in position. Owing to the deep cods carried on the top part, it was necessary to put 90 tons of weights on the top to counteract the lift when casting.

This casting was run from both ends, with one ladle holding 8 tons of metal at the shallow end of the casting and one carrying 15 tons at the deep end. Both ladles were poured simultaneously, ingates entering at the bottom of the mould. By previous calculation, it was ensured that the slides had been completely covered with metal when the 8-ton ladle was empty, and the 15-ton ladle, with additional ingates higher up, completed the filling of the mould. This method was adopted to relieve the strain on the job; relief was also given by the location of dummy risers off the shallow part of the casting. A steel-mix iron was necessary to give an analysis of T.C, 3.15; Si, 1.20; Mn, 0.60; S, 0.095, and P, 0.40 per cent.

Actually, for all the above castings, a Brinell number of 160 to 180 was insisted upon, and despite the large sections of metal involved this figure was invariably obtained. It was essen-

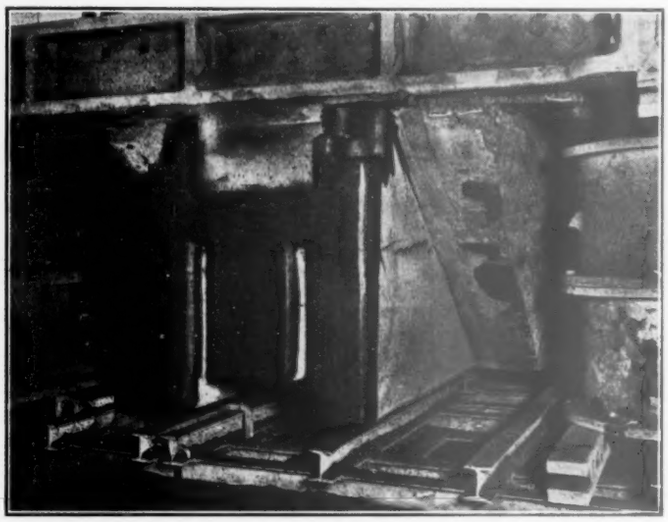

FIG. 15.—BOLTING ARRANGEMENTS FOR THE OFFSIDE BRACKET MOULD.

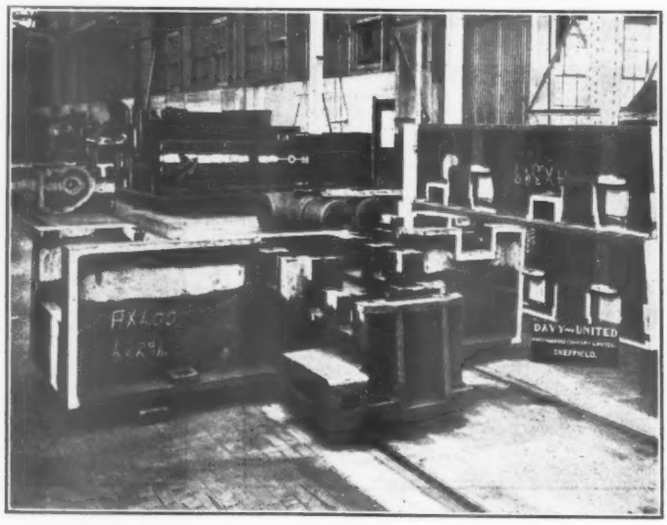

FIG. 16.—REDUCTION DRIVE FRAME.

tial, in view of the rigid requirements regarding cleanliness and soundness of the castings, that all the metal used should be melted at the highest possible temperature from the cupolas and cast as hot as possible, that is, above 1,300 deg. C. In order to achieve this, no time was lost in skimming off and conveying the metal to the jobs to enable them to be cast with the minimum delay. This applies to all high-class castings on which a great deal of machining is to be done. Some people would point out that, by following this procedure, the refractory materials of the moulds would suffer. Therefore, high-quality refractories must be employed in order to cater for the high-temperature metal, which is of primary importance.

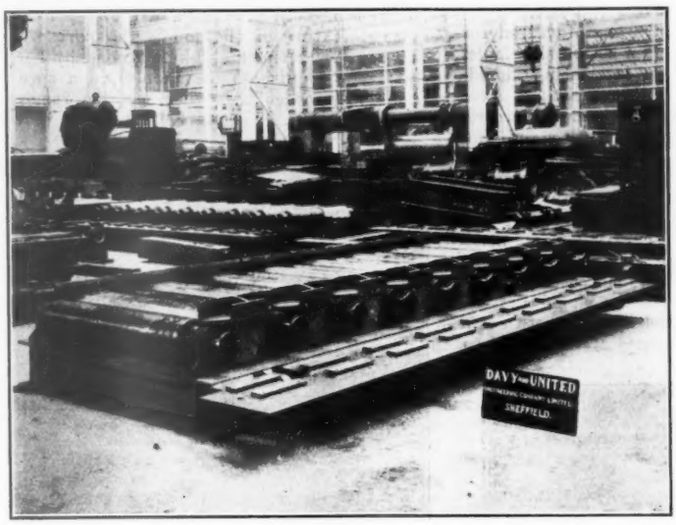

FIG. 17.—ROLLERS ASSEMBLED IN MILL TABLE.

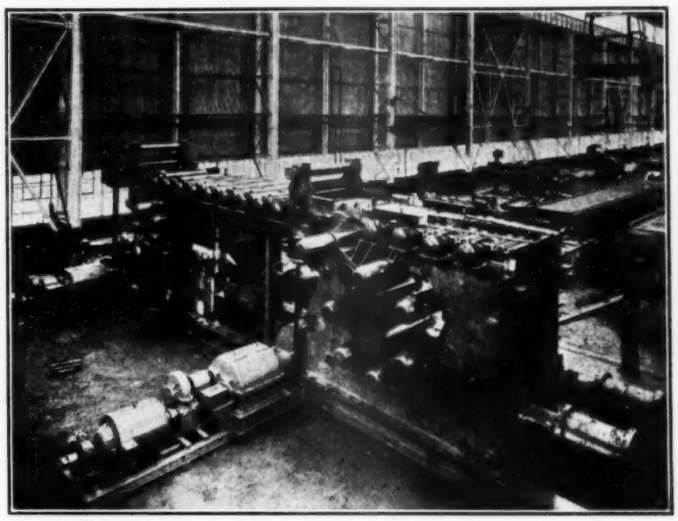

FIG. 18.—COILER FOR HOT REELS.

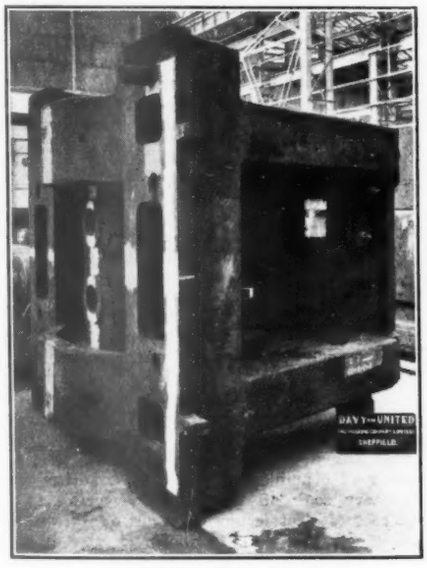

FIG. 19.—PINION HOUSING CASTING.

Rolling-Mill Castings

As mentioned at the beginning of the Paper, the foundry with which the author is associated is called upon to manufacture many types of castings, large and small, in connection with rolling-mill plant, and he is only able to consider a few examples of such castings.

A number of the castings can be made from ordinary engineering iron, with the approximate analysis of:—T.C, 3.30; Si, 1.8; Mn, 0.7; S, 0.07; and P, 0.7 per cent., where the strength and structure of the metal are adequate for the service conditions. An example of a casting made from such material is a reduction drive frame, weighing 6 tons, which is shown in Fig. 16. The main feature of this casting, from the moulding point of view, is the accurate location of the bearing and other cores.

On the other hand, with a continuous hot strip and sheet mill, there are many applications where high-duty cast irons are essential. For instance a considerable number of table rollers were manufactured, 10 in. dia. and 4 ft. 8 in. long, the metal thickness being 1 in., and each weighing 5 cwts. A Brinell hardness number of 275 to 300 was demanded of the non-heat-treated castings, and to obtain this figure an alloy cast iron was employed, having the following composition:—T.C, 2.8 to 3.0; Si, 1.6 to 2.0; Mn, 0.7; S, 0.08; P, 0.15; Ni, 1.75; Cr, 0.4, and Mo, 0.35 per cent.

FIG. 20.—PINION HOUSING AND CAP.

As these rollers were cast vertically, the moulding technique involved the use of only two $\frac{5}{8}$ in. dia. top runners, covered with perforated plates, and a 9-in. tapered head on the castings. Subsequently the castings were machined and ground on the barrel and fitted with shafts, and Fig. 17 shows some of the rollers in position in the table.

Rollers for Hot Reel Coilers

In connection with the coilers for the hot reels (Fig. 18) certain rollers 15 in. dia., 6 ft. long, $1\frac{1}{2}$ in. thick, and weighing 12 cwts. were called for, and a Brinell hardness range of from 450 to 500 was demanded. To obtain this a heat-treatment of the castings was carried out, by heating at 850 to 900 deg. C., quenching in oil and tempering at 180 to 260 deg. C. in order to relieve stresses. The metal used gave an analysis of:—T.C, 2.8 to 3.0; Si, 1.5 to 1.8; Mn, 0.7; S, 0.08; P, 0.15; Ni, 2.5 to 3.5, and Cr, 0.4 per cent.

The castings were machined all over and ground. In the foundry they were cast vertically, with 1 ft. of tapered head, and two top runners $\frac{7}{8}$ in. dia., covered with perforated plates, were used. Excellent results were obtained in both types of rollers described, by top running with the two small runners, and by pouring the metal at the highest possible temperature.

FIG. 21.—A 20-TON SLAG LADLE.

Pinion Housing

Other types of castings, owing to their size and the service required of them, necessitate the use of steel-mix irons. Such a casting, shown in Fig. 19, is a pinion housing, 36 tons in weight, cast in one piece and with the bedplate at the top. It is a job requiring very great skill in moulding and coremaking. The chief cores are

the main body core, lightening cores in the arms and the cores for the bedplate portion. It is quite unnecessary, for all the large castings mentioned in this Paper, to emphasise the importance of the attention which should be paid to all details of manufacture and to the strength of any tackle used on the jobs. A usual analysis for this type of casting is T.C, 3.25; Si, 1.20; Mn, 0.7; S, 0.09, and P, 0.4 per cent., while a 25 per cent. steel addition is customary.

Another type of pinion housing, consisting of two halves bolted together, is shown in Fig. 20, as is also the housing cap. The pinion housing

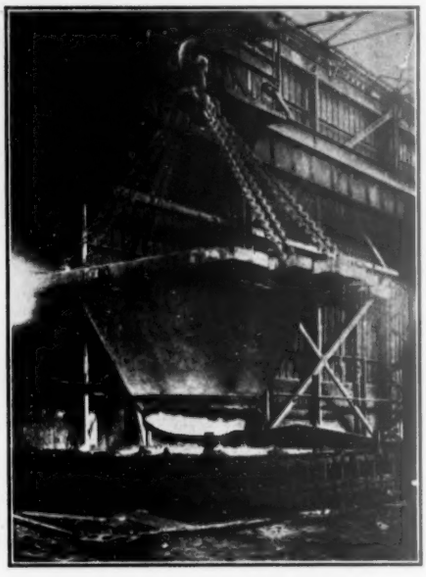

FIG. 22.—LIFTING THE TOP PLATE AND CORE FROM THE CAST-UP MOULD.

weighs 46 tons and the cap 13 tons. Each half of the housing is moulded separately, joint-flange down, and the cores in the arm have to be held down with chaplets, suitably packed, to avoid lifting. The housing cap was moulded in the position as shown with the joint-flange down, necessitating drawbacks at each side. For these castings a similar steel-mix iron was employed. In large castings particularly, the question of "feeding" is very important and, although a great deal depends on the skill of the moulder, the first consideration is the provision of hot metal for "feeding," which latter the author supplies in his foundry from a cupolette, specially operated for this purpose.

Slag Ladles

Other types of castings are manufactured for steelworks, and Fig. 21 shows a 20-ton slag ladle, in halves, which presents an interesting moulding job, as a number of these castings have been made from a semi-permanent mould and core. A skeleton pattern was provided with a splitting core print, and for the first casting the mould was bricked to the pattern, the thickness made up and the core built up inside with specially designed tackle and bolted to a strong top plate, weighing itself 18 tons. At a suitable time after casting, the top plate and core are lifted out (Fig. 22) and for all subsequent castings it is only necessary to redaub both the mould and the core with loam, all the brickwork in both cases being retained. The only parts of the mould to

FIG. 23.—CORE FOR SLAG LADLE.

be remade each time are the two drawbacks over the trunnions. Fig. 23 illustrates the core; when redaubing it, the skeleton pattern is simply lowered over the brickwork so that the core is dead accurate in shape. This casting is made from a hematite mixture, analysing usually as T.C, 3.60; Si, 1.60; Mn, 0.65; S, 0.07, and P 0.07 per cent.

Steam-Hammer Cylinder

A final example, Fig. 24, is that of a steam-hammer cylinder, weighing 6 tons, which is moulded horizontally in special boxparts and then cast vertically. A 2-ft. head was incorporated on this casting, which was run completely from the bottom, a runner entering the bottom flange. A cylinder metal was employed, the actual analysis of the castings being T.C, 3.15; Si, 1.22; Mn, 0.65; S, 0.115, and P 0.38 per cent. A special feature of the job is the port cores, which are very slender and surrounded by bulky metal; they require to be made from a special refractory in order that they may be removed without difficulty. The chief constituents of the

FIG. 24.—STEAM-HAMMER CYLINDER.

refractory material are steel moulder's composition, blacking and plumbago, and loose low-carbon iron rods are used for reinforcing the cores, thus facilitating their removal.

In conclusion, the author would take the opportunity of thanking his directors, and particularly Mr. W. Reid, for their kind permission to publish this Paper.

LIGHT-ALLOY MELTING PRACTICE

By W. C. DEVEREUX,* F.R.Ae.S., M.I.Ae.E.

The quality of light alloys of both aluminium and magnesium depends largely upon the conditions of melting, and considerable research has resulted from the realisation of the importance of this subject.

The successful casting of aluminium alloys depends upon their homogeneity, freedom from dissolved or combined gases, oxides and other non-metallic inclusions, and absolute temperature control. Magnesium alloys, on the other hand, are not greatly troubled by gas absorption, the chief difficulties being the production of metal free from dross and flux inclusions in a neutral atmosphere that will prevent oxidation and burning. These items are of primary importance, not only in maintaining a reputation for reliability, but as the largest single item affecting the costs of production. Next in order of importance are maintenance costs, fuel costs, melting losses and ease of manipulation (labour costs).

The following practical observations made during many years' working of various types of furnaces tend to show certain advantages and disadvantages for each of the many different methods adopted according to the variety of materials produced.

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Aluminium Alloys

The earliest furnaces used for aluminium alloy melting were coke-fired lift-out or pit-type furnaces. The crucible life was extremely short and where a variety of castings was made in a jobbing foundry it was extremely inconvenient to replace the crucible in the furnace to maintain temperature when sufficient moulds were not prepared to take the whole of the metal. This resulted in metal stewing at a high temperature, and combined with the frequent use of undried coke was the cause of much rejection for porosity due to gas absorption. Tilting furnaces were next used, and with dried coke excellent quality metal could be produced with a better crucible life. The storage and drying of coke are a disadvantage, however, and with the advent of oil-fired crucible furnaces the use of oil fuel superseded coke to a large extent in this country. Fuel oil is easily stored and handling is reduced to a minimum.

Town's gas is used where supplies are obtainable at sufficiently low cost, and the rather conflicting opinions as to the effects of this heating medium on the quality of the metal produced show at least that there is no obvious detrimental effect through gas absorption where metal is well fluxed and degassed. Electric-resistance heating of crucible melts is only practised on a laboratory scale in this country, owing to the high cost of electric power. Continental applications of this method show, however, that it is the ideal method of heating, as the temperature control is absolute, and there is no opportunity for contamination of the metal by products of combustion. Plumbago and carborundum crucibles have a comparatively short life, however, in alloy mixing furnaces, and contribute largely to the cost of crucible furnace melting. In addition, they are permeable to combustion products, and the greatest care is needed to obtain gas-free casts without loss of magnesium.

Low-frequency induction melting appears to be the answer to these problems, the metal being maintained in a gas-free atmosphere and in constant circulation, ensuring complete solution

of hardener alloys and freedom from segregation. The stirring necessary when mixing in a crucible furnace may cause quantities of dross and oxide to become suspended in the molten metal, with the danger of "hard spot" inclusion and porosity in the finished product. In addition, the depth of a melting crucible relative to its area of cross-section means that a covering layer of flux will afford protection to only a minor fraction of the surface exposed to the furnace atmosphere, that in contact with the crucible walls being exposed to the penetrating effect of gases in a combustion chamber at 900 to 1,200 deg. C. under the most favourable conditions.

The constant movement of the metal in an induction furnace means that a fresh surface is being continually exposed to the air, and unless precautions are taken, excessive losses by oxidation will occur. A satisfactory covering flux or an inert atmosphere (nitrogen) will prevent this effect, however, and in practice furnace losses can be reduced to approximately one-third of those obtained from a crucible furnace. Such a furnace can either be run on the batch system,

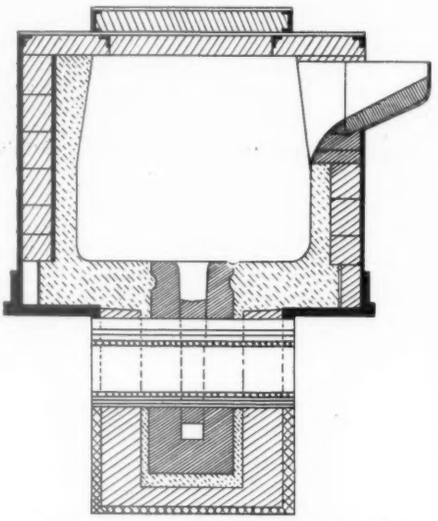

FIG. 1.—SECTION THROUGH 100-KW. LOW-FREQUENCY INDUCTION FURNACE.

where 75 per cent. of the metal is completely emptied from the furnace and a fresh charge added, or for continuous working where one ingot or casting can be poured every few minutes, and the equivalent weight of new material added, which is completely melted and mixed in time for the next pour. A crucible furnace is limited to batch operation, as, owing to the inability to control waiting metal within reasonable temperature limits, the exposure to furnace atmosphere, and the stirring necessary for mixing, a steady deterioration of metal is realised when these conditions are attempted.

Table I gives a comparison of two furnaces in the same foundry, one a low-frequency 100-kw. induction furnace, the other an oil-fired crucible furnace. Both were worked 24 hrs. per day over an extended period, and were capable of a similar output, *i.e.*, 4 to 5 tons per day, depending on the type of casting produced.

A section through the 100-kw. induction furnace is shown in the diagram, Fig. 1.

Melting losses vary according to the technique peculiar to individual foundries, and although they constitute an important factor in costing, may sometimes indicate careful skimming and fluxing procedure. A good flux, however, should separate dross from metal, and if undue turbulence and "frothing" of metal are avoided, oxidation losses can be kept low. The following analysis of losses from an ingot foundry employing oil-fired crucible furnaces of 500 to 1,200 lbs. capacity gives some idea of where the metal is lost and how improvements may be effected:—

	Per cent.
(1) Melting and pouring crucible clearings	0.36
(2) Splashings	0.47
(3) Metallic dross (furnace skimmings)	0.30
(4) Skimmings (ladle)	0.57
(5) Oxidation losses not accounted for	0.5 to 1.7 (Variations too great to obtain.)
(6) Metal lost on pot failures ..	0.28 (Average figures.)

Other sources of loss occurring intermittently or in widely varying amounts may reach the following figures on individual casts:—

Excess of charge over material required, 1.04 per cent.

Metal overflowing from furnace spout, 0.49 per cent.

(Average of casts showing abnormal loss only.)

A cost comparison between three different types of heating gives the following figures, working continuously on similar castings, and taking the oil-fired crucible furnace as a basis at 100 units:—

	Oil-fired crucible.	Coke-fired crucible.	Low-frequency induction.
Metal losses ..	55.0	56.5	28.8
Fuel or power ..	21.20	14.04	36.3
Maintenance ..	23.8	18.66	5.9
	100.00	89.2	71.0

Power costs, 0.73d. per unit. Oil costs, 3¾d. per gallon. Coke costs, 38s. per ton.

The high maintenance costs of the crucible furnaces are due to the replacements of crucibles, which have a life of 10 to 14 days continuous working, whereas the induction furnace lining will last at least six months and occasionally longer. The initial cost of an induction melting furnace is about 20 per cent. higher than a crucible furnace of similar capacity, and installation charges are considerably higher.

Further advantages, however, are that the foundry is kept clear of all fumes and dirt, fatigue effects on the operators being noticeably

TABLE I.—*Performance Data on Two Types of Furnace.*

	Oil-fired crucible furnace.	Low-frequency induction furnace.
Capacity	1,100 lbs. ..	1,760 lbs.
Working content	1,100 „ ..	1,300 „
Consumption ..	12 to 15 galls. oil per hour	14 to 25 kw.-hr. maintenance load (100 kw.-hr. max. load).
Melting rate ..	550 to 750 lbs. per hour	600 to 800 lbs. per hour.
Output	4 to 5 tons per day	4 to 5 tons per day.
Melting loss ..	1.9 per cent. ..	0.5 to 0.8 per cent.
Total foundry losses	3.6 per cent. ..	1.2 to 1.5 per cent.

reduced, making a marked difference in production per man, time lost by illness, and care in operation.

Open-Hearth Furnaces

Where large quantities of one alloy are mixed and ingoted prior to remelting for castings, it is of advantage to melt larger casts than can be accommodated in either the crucible or induction furnace. Identification of castings with the original material is rendered simpler, and the number of check analyses per day is reduced. This is effected with the open-hearth type of furnace, which is adequately discussed in principal and detail by Zeerleder in "The Technology of Aluminium and Its Light Alloys" (1936).

Open-hearth melting may be done by means of oil, town's gas or producer gas, coke or electricity. With flame heating, a thin arch may separate the products of combustion from the metal, or, alternatively, the metal may be protected by a thick layer of covering flux. There is always some danger, however, of gas absorption by the metal, which is overcome where electricity supplies can be cheaply obtained by electric-resistance heating. Crushed carborundum resistors are preferable to metal elements, as the latter are liable to rapid deterioration in the presence of gases from reactive flux salts or by contamination from the actual flux or splashed metal.

Puddling of the bath of metal must be resorted to in order to assure complete mixing and absence of segregation in alloys, and this tends to mix oxide films with the metal, with a certain amount of danger of inclusions at a later stage. Tilting devices are adopted on most open-hearth furnaces at the present day to enable quiet pouring into the ladle where it is customary to make magnesium additions prior to casting. The addition of magnesium to the main bath of metal is not very satisfactory, varying losses being experienced due to oxidation and to reaction with the flux salts. During the addition of magnesium and possible degassing in the ladle there is considerable temperature loss to be added to that lost in transferring the metal from the melting furnace. This makes it necessary to run an open-hearth furnace slightly hotter than is strictly desirable, and unless very carefully controlled may cause difficulties through the production of porous or gassy metal.

Many of the difficulties of the open-hearth furnace are overcome by the rotary cylindrical type. The cylinder has a refractory lining which is heated by direct contact with the gas or oil flame, the surface of the metal in the bottom being protected by a layer of molten flux. The furnace is slowly revolved, the heat from the walls being transferred by direct conduction to the metal, instead of by radiation. In addition, the need for puddling is largely obviated, the gentle turning having a mixing effect which not only prevents melt segregation, but ensures that the whole of the molten metal is brought into contact with the flux layer so that the alloy produced is largely free from oxide inclusions or absorbed gas.

Bulk melting in open-hearth or rotary type furnaces, whether on the batch principle, or continuously, means economies in fuel or power because of the direct heat transfer, and also on equipment and plant, the furnace lining lasting from six to twelve months. There is some reduction of silica in the furnace lining, but this does not cause rapid deterioration, nor is the "pick-up" of silica in the melts noticeable. The melting in bulk lots of from 2 to 10 tons means a great simplification in identification with cast numbers and testing procedure at later stages in manufacture, and means that larger quantities of the finished article are obtained with identical composition and properties, which is an economic and technical advantage when supplying materials to government specifications.

For the remelting of ingot material, bowl furnaces have much to recommend them where the casting programme is such that continuous working can be adopted, as the temperature of the metal is found to be much more controllable than with crucible furnaces, and metal transfer can be made with the minimum of turbulence and oxidation. In general, however, this type of melting can only be employed for die-castings and small sand-castings where the quantity of metal removed at any one time is small in comparison with the bulk of metal melted, and can conveniently be transferred with a hand ladle. The metal can then be maintained for long periods at a few degrees above the casting temperature, continuous additions being made

which have little cooling effect, and with a well-constructed furnace under conditions where absorbed gases are liberated. The accessibility of the surface assists periodic fluxing and enables a ladle to be introduced without causing the surface skin of oxide to be mixed with the charge. Iron crucibles may safely be used with these furnaces, there being little erosion or washing action of the metal provided they are carefully cleaned and coated with a suitable clay or whiting wash every 24 hours.

Magnesium Alloys

The melting technique employed for magnesium base alloys has already been discussed by the author in his Paper* to the Foundry Congress in Warsaw last year. It is again emphasised that the essential point in the melting of the metal is its extreme reactivity with both oxygen and nitrogen in the molten state, and it must therefore be protected from the air by means of a controlled atmosphere and fluxes. Crucible melting is therefore adopted for general foundry work, where the small surface area compared to the bulk of metal is easily covered with a layer of protective flux during the melting period. The flux performs the double purpose of cleansing the metal from oxide inclusions when intimately mixed by stirring, and then protecting the surface from further oxidation by rising to the top and setting in a hard cake, which may be removed just before casting.

Furnaces for magnesium melting are therefore limited in scope by the characteristics of the metal, and can be grouped in two general types:

(1) Crucible furnaces employing iron pots either of the lift-out or tilting type. The lift-out furnace is preferred in order to avoid unnecessary decanting of metal with consequent oxidation.

(2) Bale-out bowl furnaces with a totally enclosed top, into which an atmosphere of SO_2 gas can be admitted to protect the metal, the flux employed being of greater density than the molten metal in order to leave the surface accessible for ladling-out.

The type of heating does not in general affect the quality of the castings produced, and is chosen for economy, availability and ease of control.

* "Foundry Trade Journal." Vol. 59 (1938), p. 218.

THE EFFECT OF MELTING CONDITIONS ON LIGHT ALLOYS

By A. J. MURPHY,* M.Sc., S. A. E. WELLS* and R. J. M. PAYNE,* B.Sc.

There is a general recognition nowadays of the important *rôle* played by the conditions prevailing during melting in the production of aluminium and magnesium alloy castings of high quality. The present communication describes some observations on this aspect of metallurgical control which have come under the authors' notice and which it is hoped may be of interest in a discussion of melting conditions as they affect foundry processes.

Equipment

On comparing notes of the experience of different foundries, it is found that satisfactory results are obtained from a large variety of fuels, furnaces and crucibles, and the ultimate choice from among these is often governed by local conditions, such as the relative costs of oil, gas and coke or the maximum and minimum weights of castings to be produced. The plant with which the authors are concerned comprises separate foundries for sand-casting and die-casting and for aluminium alloys and magnesium alloys. Oil-burning crucible furnaces are used throughout; for aluminium alloys the crucibles in the stationary bale-out furnaces are of graphite-clay, and those in tilting furnaces are of cast iron; pressed steel crucibles are used for magnesium alloys both in tilting and stationary furnaces.

EFFECT OF MELTING CONDITIONS ON COMPOSITION

(a).—Contamination

The absorption of gases by molten metals is a form of contamination, but in ordinary foundry usage the term is limited to the entry into the metal of non-gaseous impurities. An obvious potential source of such impurities is the crucible. Since both aluminium and magnesium are strong reducing agents at elevated temperatures, they present the possibility of contamination by reduction of oxygen-containing refractory materials and the alloying of the reduced element, *e.g.*, silicon, with the light metal. In the case of cast-iron and steel crucibles, the danger of contamination by iron through direct alloying with the material of the crucible has also to be considered. In both these respects there is a sharp distinction between aluminium and magnesium-base alloys.

(i).—Aluminium Alloys

As far as the authors are aware, no case of contamination of the normal industrial aluminium alloys through reaction with graphite or silicon-carbide crucibles has been recorded, and certainly no instance of such contamination has occurred within their own experience. This is true both in the presence and absence of fluxes during the melting operation.

Cast iron presents advantages in certain respects over refractory clays as a material for crucibles in the aluminium foundry, notably in better thermal conductivity, superior strength, lower cost and greater facility of production. On the other hand, precautions which are unnecessary in the case of fireclay crucibles have to be observed constantly with iron melting vessels, if contamination of the aluminium alloy with iron is to be avoided. A wash consisting of whitening 10 lbs., water 5 galls. and sodium silicate 6 ozs., applied by brushing to the inside of the crucible, is found to be effective for furnaces which are completely emptied after each melt. It is necessary to renew the wash daily, and if this is carried out conscientiously no appreciable pick-up of iron occurs.

It is an undeniable criticism of the use of iron melting pots that the avoidance of this contamination is dependent upon the protective wash being applied and renewed with care by the fireman or other operator charged with this responsibility. Two instances may be cited to illustrate the serious consequences which may result from contamination of aluminium alloys by iron.

After suitable modification, aluminium-silicon alloy containing silicon 12 per cent. and iron 0.3 per cent., when cast into the usual 1-in. dia. dry-sand mould, shows a fine-grained fracture and mechanical properties of which the following are typical: maximum stress 11 to 12 tons per sq. in. and elongation on $4\sqrt{A}$ 10 to 15 per cent. If melted in a crucible of grey cast iron without a suitable protective coating, the iron content may readily increase to 1 per cent. With this proportion of iron the alloy shows a bright "crystalline" fracture, with large lustrous facets, and the mechanical properties of a sand-cast test-bar become: maximum stress 9 to 10 tons per sq. in., and elongation on $4\sqrt{A}$ 2 per cent. The loss of ductility is a particularly undesirable feature.

The second case in which reference may be made to the effect of iron contamination is that of the aluminium alloy containing copper 4 per cent., with titanium up to 0.2 per cent. This has been introduced recently for aircraft applications under the provisions of specification D.T.D. 304. In order to attain the mechanical properties specified, namely, a maximum stress of not less than 18 tons per sq. in. and elongation not less than 4 per cent., it is important that the iron content of the alloy shall not exceed about 0.2 per cent. This alloy is therefore very sensitive to contamination from iron crucibles, and experience in production has shown that if from this or any other cause the iron content rises to 0.35 per cent., the desired properties cannot be attained.

(ii).—Magnesium Alloys

Molten magnesium reacts readily with siliceous materials such as fireclay, reducing silica and silicates, the silicon thus produced alloying immediately with the magnesium. No data are available regarding the quantity of silicon which can be absorbed in this way, since fireclay crucibles are never used for magnesium alloys, but it is a well-established fact that if adherent moulding sand is not thoroughly removed from runners and risers before they are remelted, the silicon content of the resulting metal will increase in extreme cases to as high as 1 per cent., as compared with an original value of about 0.1 per cent.

In complete contrast to aluminium, the normal magnesium alloys appear to be practically inert as regards any tendency to alloy with iron, at least up to a temperature of 900 deg. C. This permits crucibles of unlined steel to be used in the magnesium foundry, and the same material can be used for ladles and stirrers. The fluoride and chloride fluxes employed do not affect this reluctance to alloy with iron, and even after repeated fusions of the same charge in one steel crucible no increase of iron content can be detected. The presence of manganese—about 0.3 per cent.—in the magnesium alloy is considered to assist in preventing absorption of iron.

(b).—Change of Composition

Even when contamination, *i.e.*, invasion of the metal by foreign impurities, has been prevented, there remains the possibility of the composition of the charge being altered by the loss of one or more of the constituents during melting, just as phosphorus or zinc can be lost from bronzes and brasses. In general one does not have to contend with volatilisation in alloys of aluminium or magnesium, but the investigation now to be described briefly shows how a change of composition can occur, from other causes, in certain aluminium alloys.

The object of the experiments was to ascertain if any loss of magnesium occurred either when flux degasification treatment was applied to a melt or when the melt was subjected to ordinary melting only without fluxing. Alloy Ceralumin "B" (D.T.D. 287), having the original composition:—Copper, 1.3; silicon, 2.2; nickel, 1.3; magnesium, 0.1; iron, 1.0; niobium, 0.1 per cent., aluminium remainder, was chosen for the investigation, and the effect of repeated application of flux and the influence of remelting several times without flux were examined.

The fluxing experiments were carried out on a single 20-lb. melt, which was treated four times with a dry flux mixture of 2 parts sodium chloride and 1 part sodium fluoride, using 2 per cent. by weight of the salts mixture on each occasion. At each stage the temperature of the metal was raised to 750 deg. C. for fluxing, and after fluxing cooled to 700 deg. C. to enable two standard test-bars to be poured. The heads of the test-bars were cut off and returned to the crucible to maintain an approximately con-

* J. Stone & Company, Limited, London.

stant area of surface of metal exposed to the action of the flux. The quantity of the metal treated therefore only varied by a few ounces, the amount required for the test-bars.

The remelting experiments without flux were also made on a single 20-lb. melt. The procedure was to raise the temperature of the melt to 750 deg. C., cool to 700 deg. C. and cast two standard test-bars and then pour off the remainder into ingot moulds, the ingots and the heads cut from the test-bars being remelted at each stage. Three stages of remelting were carried out in all.

Samples consisting of turnings from the complete cross-section at the top of a test-bar representative of each stage of the experiments were taken for determination of the magnesium content in both the fluxed and non-fluxed series.

The normal heat-treatment for Ceralumin "B," consisting of heating for 11 hours at 165 deg. C., was applied to the test-bars before making mechanical tests. Brinell hardness determinations were also made on pieces in the "as-cast" condition, as it was thought that some difference might be observed even at this stage if any marked loss of magnesium had occurred. The results of the chemical analyses, Brinell hardness determinations and tensile tests are given in Table I.

TABLE I.—*Effect of Repeated Melting—Ceralumin "B."*

	Repeated fluxing.						Repeated remelting without flux.			
	Mg per cent. by analysis.	"As cast." Brinell hardness, 10/1000/15.	Heat-treated. Brinell hardness, 10/1000/15.	0.1 per cent. proof stress. Tons per sq. in.	Ultimate stress. Tons per sq. in.	Elongation per cent. on 2 in.		Mg per cent. by analysis.	"As cast." Brinell hardness, 10/1000/15.	Heat-treated. Brinell hardness, 10/1000/15.
1st fluxing	0.10	65	82	7.04	12.00	4	Original melting	0.12	63.5	79
				7.04	11.80	3.5				
2nd fluxing	0.08	61.5	78	6.88	11.40	3	1st remelt	0.12	63.5	81
				6.60	11.40	3				
3rd fluxing	0.08	58.5	75	5.92	10.92	4	2nd remelt	0.11	62	80
				5.24	10.32	4				
4th fluxing	0.06	58	67	4.64	10.32	5	3rd remelt	0.12	62	79
				4.93	10.53	5				

Tensile tests were not carried out on the "remelting series" as it was obvious from the chemical analysis and hardness tests that no loss of magnesium had occurred.

The first series of experiments show conclusively that a serious loss of magnesium can occur from a repetition of the fluxing treatment, resulting in a softening of the alloy, the effect being marked on all the mechanical properties examined. It is clear, therefore, that, if for any reason a melt of an aluminium alloy containing magnesium is treated more than once, or at the most twice, with a flux of the type described, an addition of magnesium should be made to compensate for the loss due to the action of the flux. The same consideration has to be borne in mind if remelted runners and risers constitute a large proportion of the charge, a condition which is likely to arise when the metal ratio on a job is high, *i.e.*, when the weight of the untrimmed casting is large compared with that of the finished casting.

The results of the second series of tests indicate that in the absence of flux, there is no loss of magnesium on repeated melting. Observations on aluminium-base alloys of higher magnesium content, such a Y-alloy containing 1.5 per cent. magnesium, show that they behave in the same way as Ceralumin "B," the actual loss of magnesium with repeated fluxing being greater, as would be expected.

It is a little surprising, in view of these results on aluminium-base alloys, to find that, with magnesium-base alloys containing 8 to 10 per cent. of aluminium, there is no change of composition even after many repetitions of melting under fluxes containing fluorides and chlorides. It is true that, although they contain chlorides and fluorides, the fluxes used for magnesium-rich alloys are not of the same composition as that applied to the aluminium alloys in the present investigation, and it is also conceivable that a more complex flux might be evolved which would not exert a preferential action on the magnesium in aluminium-rich alloys.

EFFECT OF TEMPERATURE ATTAINED BY THE MOLTEN METAL

Just as the alloys of aluminium and those of magnesium differ from each other in their requirements as regards melting vessels and in the effect of flux treatment, so it is also necessary to deal with them separately when considering the effect of the maximum temperature to which the melt is heated before casting.

(a).—Aluminium Alloys

It is generally accepted that when melting aluminium alloys in the foundry, the temperature should not be raised unduly beyond the level required to give a reasonable speed of working and to ensure the correct casting temperature in the metal after it has been removed from the furnace. The principal reasons for avoiding high melting temperatures are usually considered to be the reduction of melting losses through oxidation and the avoidance of gas absorption, the solubility of hydrogen in molten aluminium increasing rapidly with rise of temperature. Fuel consumption and crucible life are also adversely affected by excessive heating of the charge.

The authors have notice that there is another consequence of high melting temperatures which may be of importance in certain circumstances and which is perhaps not generally realised. This is the effect of melting temperature on the grain size of sand castings.

Whereas with careful working aluminium alloys may be heated to as high a temperature as 800 deg. C., even in furnaces burning gas or oil, without absorbing a harmful amount of hydrogen, there is reason to believe that in many alloys the grain size of sand castings is considerably larger if the temperature of the melt has exceeded 750 deg. C. than if it has been maintained at a lower value. This effect is quite distinct from the influence of pouring temperature: in the alloys under consideration a coarse grain is produced if the temperature of the melt has exceeded the critical value of 750 deg. C., even though the actual casting temperature is about 720 deg. C.

A coarse-grain structure is undesirable for various reasons: it shows its influence first in causing a tendency for intercrystalline cracking to occur during the cooling of the casting in the mould, and possibly before solidification has been completed. This cracking is not to be confused with the weakness commonly known as "hot-shortness." Hot-shortness is more characteristic of a particular composition of alloy, and is present under all conditions of melting, whereas the feature now being described is avoided if the melting temperature is not allowed to exceed 750 deg. C.

Metal which has suffered a coarsening of grain through overheating during melting can be corrected by casting into chill moulds, *i.e.*, by ingotting and remelting below the critical temperature.

Fig. 1 illustrates the phenomenon in an alloy having the composition: Copper 2.5, nickel 1.5, iron 1.2, silicon 1.2, magnesium 0.8 per cent., and aluminium remainder. The macro-etched sections shown were taken from sand-cast plates 6 in. by 2 in. by ¾ in., all of which were cast at a temperature of 720 deg. C. after heating the melt to the various temperatures indicated. The sudden increase in grain size when the melting temperature passes 750 deg. C. is clearly seen. Precisely similar behaviour has been noted in the case of simple alloys of aluminium with 8 per cent. of copper, and it probably occurs also in other alloys.

Much more experimental evidence would be required before a satisfactory explanation of this effect could be formulated, but it is difficult to avoid the speculation that it may be connected with the formation of nuclei in the fluid metal below a temperature of 750 deg. C., and their disappearance at higher temperatures. It is a matter of conjecture whether these nuclei are particles of a solid phase which liquefies on heating above 750 deg. C. or whether they are merely centres formed by the grouping together of atoms in the liquid metal, but if either of these ideas be correct it still remains to account for the failure of the nuclei to re-form in the melt when the temperature falls below 750 deg. C. once more.

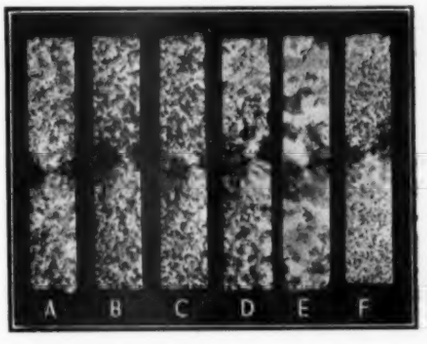

FIG. 1.

A = Max. temp. melt 720 deg. C., cast 720 deg. C.
B = " " " 740 " " "
C = " " " 750 " " "
D = " " " 760 " " "
E = " " " 800 " " "
F = " " " 800 deg. C., ingotted, remelted 730 deg. C., cast 720 deg. C.

In any investigation of the relation between melting conditions and grain size, it is necessary to guard against the spurious effects which can be introduced by dissolved gas. The escape of gas from the cooling metal as it approaches the freezing point and during solidification causes agitation, which in itself produces a certain degree of grain refinement. It is therefore essential to eliminate this factor, by ensuring that the molten metal is substantially free from dissolved gas, when the influence of other variables is to be studied.

There are many occasions in the aluminium foundry when it is not convenient, or not possible, to operate under such conditions that the temperature of the molten metal does not exceed 750 deg. C. One need only mention the cases where a pouring temperature above this value is required for a casting having thin sections

in some parts. It is clearly necessary, therefore, to consider what alternative means there are of securing a fine grain in castings without seriously restricting the melting procedure.

Benefits of Fine Grain

It may be useful at this stage to review the benefits which follow from a fine grain size. The

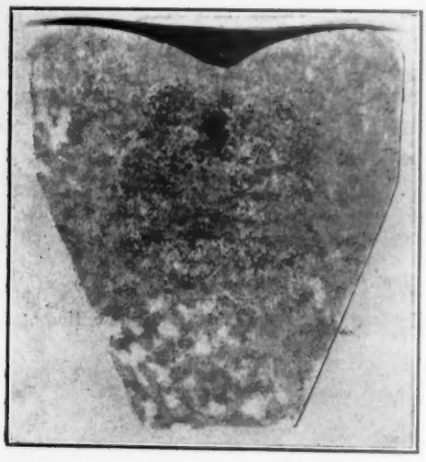

FIG. 2.—UNREFINED. CAST 800 DEG. C.

grain referred to here is the grain of the macro-structure, which is revealed by simple etching of machined surfaces and is visible to the naked eye. The founding properties of aluminium alloys are improved when the metal is intrinsically fine-grained, since the risk of cracking in the mould and the tendency towards shrinkage porosity are reduced. The latter advantage appears to result from the greater facility with which metal solidifying with a fine grain "feeds down" from risers during the freezing of the casting. This is especially important in high-strength aluminium alloys, which are always characterised by a large contraction of volume in the transition from the molten to the solid state. In the same alloys heat-treatment by quenching from 500 to 530 deg. C. is often in-

FIG. 3.—REFINED. CAST 800 DEG. C.

volved, and here again a small grain size reduces the danger of cracking.

When considering the mechanical properties of actual castings, the most important effect of grain refinement is not in conferring high values of strength, but in the greater consistency of properties in the different parts and varying sections.

Although a number of different processes, of a more or less elaborate nature, have been proposed for ensuring a fine grain in aluminium-alloy castings, there is no doubt that the most easily applied method is that of incorporating in the alloy an element which by its presence produces a small size of macro-grain. From among a dozen elements which have been investigated from this point of view, niobium (or columbium) and titanium stand out as the most effective in their grain-refining action. During the past three or four years the authors have been largely concerned with the application of niobium, and the notes which follow refer to the grain-refining influence of this element in relation to melting conditions.

The efficiency of any grain-refining addition in aluminium alloys can be tested and demonstrated by casting the metal containing the addition from a high temperature into a mould which ensures slow solidification; these are the conditions best calculated to produce a coarse grain size if any tendency in this direction exists. For most aluminium alloys, suitable conditions for this test are obtained by pouring the metal at a temperature of 800 deg. C. into a dry-sand mould producing a cylindrical block 3 in. dia. and 3 in. high. In order to avoid too much dispersed unsoundness the mould may be tapered at the base to have the form shown in Figs. 2 to 4. The grain size is revealed by sectioning the block along its central axis, machining one of the flat

FIG. 4.—REFINED. MAINTAINED 900 DEG. C. FOR 4 HRS., CAST 900 DEG. C.

surfaces smooth in a lathe and etching in a suitable reagent.

As an illustration of this grain-refining action the effect of niobium on an alloy having the composition: Copper 2.5, nickel 1.5, magnesium 0.8, silicon 1.2, iron 1.2 per cent. and aluminium remainder, may be cited.

When a gas-free melt of this alloy is cast into the test mould under the conditions described above, grains of 2.5 to 5 mm. diameter are visible in the macro-structure. If, however, 0.1 per cent. of niobium is present in the alloy, the grain diameter is reduced to 0.2 to 1.0 mm. The effect is illustrated in Figs. 2 and 3.

Similar refinement results from the addition of 0.1 per cent. niobium to pure aluminium, simple alloys of aluminium containing up to 8 per cent. copper, the binary alloys of aluminium with magnesium contents up to 10 per cent., copper-free alloys of aluminium with magnesium and zinc, and a wide range of aluminium alloys containing copper, nickel and magnesium with various amounts of iron and silicon.

A grain-refining effect is noticeable with as little as 0.02 per cent. niobium, and the degree of refinement increases with increasing niobium additions until 0.10 per cent. is present. Raising the niobium content above this proportion does not produce any further refinement, so that in practice 0.1 per cent. is employed.

The stability in relation to melting temperature of the grain refinement due to niobium has been investigated, and it has been found that not only can the alloy be heated to 900 deg. C. without impairing of the grain-refining effect, but it can also be held at this temperature for 4 hrs. and still maintain the fine grain-size. Fig. 4 shows a section of a test block which has been kept at 900 deg. C. for 4 hrs. before pouring at this temperature. It will be seen that it is still

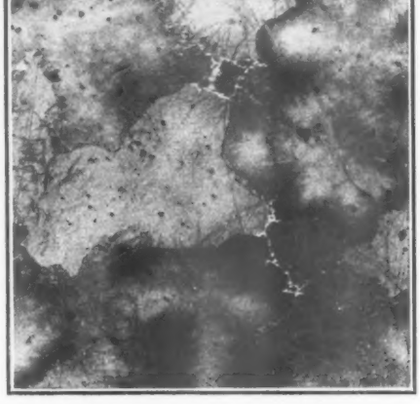

FIG. 5.—ELEKTRON A.Z.91. SUPERHEATED 750 DEG. C., CAST 680 DEG. C., HEAT-TREATED. × 60.

characteristically fine. A fair amount of dispersed shrinkage is shown in addition to the major cavity, but this is only to be expected considering the high pouring temperature and the fact that the block is entirely unfed.

It can be seen from the foregoing observations that when using an aluminium alloy which is intrinsically fine-grained, on account of the presence of a special element, the founder is relieved of one serious restriction in melting conditions, namely, the necessity for maintaining the temperature of the melt below the critical level above which grain-coarsening occurs. This is not to say that the other advantages of low melting temperatures, such as decreased gas absorption, do not remain, but a greater latitude in working conditions is certainly permitted.

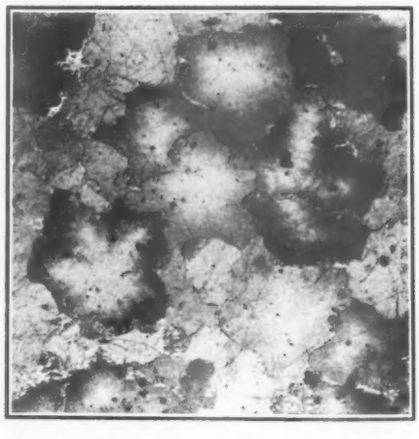

FIG. 6.—ELEKTRON A.Z.91. SUPERHEATED 800 DEG. C., CAST 680 DEG. C., HEAT-TREATED. × 60.

(b).—Magnesium Alloys

Still another difference in melting technique as between aluminium and magnesium alloys has to be noted in discussion of the effect of the temperature attained by the melt. In aluminium alloys the physical characteristics of the castings are adversely affected if the molten metal is raised to a high temperature, unless special measures be taken to counteract this

effect. As a complete contrast, in the case of all the normal magnesium alloys, it is necessary, in order to attain the best properties in the castings, to raise the temperature of the metal, shortly before casting, to a temperature of 850 to 900 deg. C. This is an essential process in the treatment of the Elektron series of magnesium alloys: it has no relation to the casting temperature, which is adjusted after superheating and is usually considerably lower.

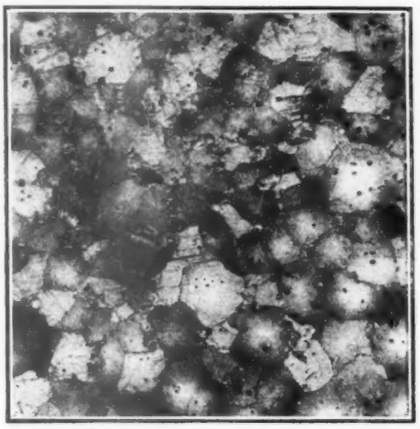

FIG. 7.—ELEKTRON A.Z.91. SUPERHEATED 850 DEG. C., CAST 680 DEG. C., HEAT-TREATED. × 60.

The practical effect of the superheating treatment is to produce a marked refinement of the grain size in the castings, with a corresponding improvement in mechanical properties. The grain refinement can be seen in fractures, in the macro-structure of etched sections and also in the microstructure. An indication of the degree of refinement is given by a series of observations made on sand-cast Elektron A.Z. 91 alloy, having the composition: Aluminium, 9.7; zinc, 0.6; manganese, 0.3 per cent. and magnesium remainder.

Four samples of this alloy were drawn from a single original melt. Each of the samples was fluxed in the normal manner, but a different superheating temperature was applied in each case: the first was heated to 750 deg. C., the second to 800 deg. C., the third to 850 deg. C., and the fourth to 900 deg. C., the duration of superheating being the same throughout. Standard 1-in. dia. bars were cast at 680 deg. C. in sand moulds from each melt, and all the bars were finally heat-treated together in the same manner. The heat-treatment consisted of heating the bars for 20 hrs. at 420 deg. C., quenching in water, re-heating for 16 hrs. at 175 deg. C., and finally quenching again in water.

Figs. 5, 6, 7 and 8 show the microstructures of these bars at a magnification of 60 diameters, and demonstrate the reduction of crystal size

TABLE II.—*Influence of Superheating on the Mechanical Properties of an Elektron Alloy.*

Superheating temp. Deg. C.	0.1 per cent. proof stress. Tons per sq. in.	Max. stress. Tons per sq. in.	Elongation per cent. on $4\sqrt{A}$.
750	8.9	15.6	1.2
800	9.4	16.35	1.0
850	9.68	18.6	1.9
900	9.3	17.5	1.3

which results from superheating the molten metal to a temperature of 850 deg. C. or higher. Table II summarises the mechanical properties, each result given being the average from four test-bars.

The metal must be cast without undue delay after superheating, as the grain size becomes coarse again if the melt is allowed to remain for an excessive period at a low temperature. This reversion is noticeable, for instance, in Elektron A.Z. 91 alloy which has been held for 30 mins. between 650 and 700 deg. C., and there is a corresponding deterioration in mechanical properties. Another factor which has to be taken into account is the grain size of the metal originally charged into the crucible. A fine grain at this stage facilitates the production of the finest possible grain after remelting and casting. This is an interesting example of the persistence of a grain characteristic through a melting operation.

The authors have been concerned in the present Paper with the influence which melting conditions in the light-alloy foundry can have on the composition and purity of the metal and on the physical characteristics of the castings. The examples and data which have been quoted have been drawn from experience in the technical control of aluminium and magnesium foundries; it is hoped that, for this reason, the Paper may be of some interest to others concerned with the industrial production of light-alloy castings. At the same time, the interrelation between the thermal history of the molten metal and the grain size in the solid state raises questions which seem to call for fundamental metallurgical research. The authors would feel that their communication had served a useful purpose if it could provide some stimulus in this direction.

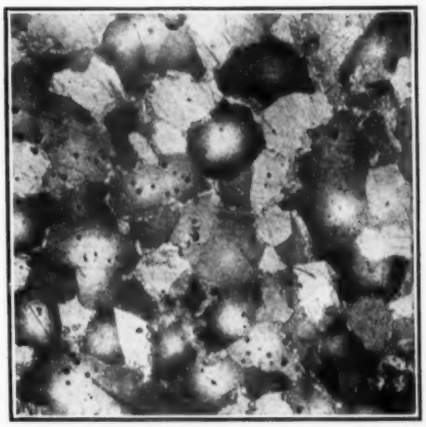

FIG. 8.—ELEKTRON A.Z.91. SUPERHEATED 900 DEG. C., CAST 680 DEG. C., HEAT-TREATED. × 60.

Acknowledgment

The thanks of the authors are due to the directors of J. Stone & Company, Limited, for permission to publish the results of the investigations reported in this Paper.

SOLUTION HEAT-TREATMENT OF ALUMINIUM CASTING ALLOYS

By Dr.-Ing. R. IRMANN*

Although the hardening of aluminium forging alloys by means of solution heat-treatment has been known since the invention of Duralumin in 1906, and has been applied technically since about 1910, yet the solution heat-treatment of aluminium casting alloys for the purpose of improving their strength did not come into practical use until after the discovery of "Y alloy" by Rosenhain in 1917. As shown in Fig. 1 the historical development of aluminium casting alloys is in part due only to the technological point of view. The aluminium casting alloys may be classified as follows:—

Group I.—Alloys to which hardeners such as Cu, Zn, Mg and Si are added which improve the strength and corrosion resistance of the alloy. (*a*) Improvement of strength by adding Cu and Zn (Al-Cu and Al-Zn-Cu). (*b*) Improvement of strength and corrosion resistance by means of Mg (Al-Mg). (*c*) Improvement of strength and of casting properties by means of Si; unsuitable for sand casting unless the grain is refined simultaneously by means of a refining with Na (Al-Si).

Group II.—Alloys to which Cu, Mg, Si are added for the purpose of obtaining a hardening effect (Al-Cu-Ni, Al-Cu-Mg, Al-Mg-Si, Al-Si-Mg, and Al-Mg).

Group III.—Alloys to which small quantities of an element such as Ti are added for the purpose of refining the grain and improving the mechanical properties, particularly by solution heat-treatment.

This classification shows that high strengths are only obtained in Groups II and III, which are subjected to a solution heat-treatment.

Heat-Treatment Processes

Solution heat-treatment can be applied only to alloys containing a constituent, the solubility of which increases with rising temperature. As shown in Fig. 2, Cu, Si, Mg_2Si, Zn and MgZn, are such constituents. The solution heat-treatment consists in annealing the alloy at a temperature ranging above the solubility curve of the added element, so that this element becomes soluble. At a temperature of 550 deg. C., for instance, about 5.5 per cent. Cu becomes soluble. By means of quenching the alloy from this temperature, the precipitation of the added element Cu is prevented, so that at room temperature a homogeneous solid solution of an unstable nature and containing 5.5 per cent. Cu is obtained.

The solid solution now has the tendency of acquiring a state of stability by means of precipitating the surplus Cu, thus producing changes in the space-lattice and a hardening effect. In the case of some alloys, this increased hardness is already noticeable when aged at room temperature, and with others only after precipitation heat-treatment. The solution heat-treatment, and the ageing at room temperature and precipitation heat-treatment, are shown diagrammatically in Fig. 3.

Furnaces for Solution Heat-Treatment

The temperatures necessary for the solution heat-treatment of casting alloys are very close to the solidus point; therefore, very uniform temperatures ranging between about ± 5 deg. C. are required. Likewise, the temperature for the precipitation heat-treatment (say, for instance, 160 deg.) which follows upon the solution

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heat-treatment and quenching must of necessity be within a range ± 3 deg. C.

If, therefore, a maximum solution heat-treatment temperature of 500 deg. C. is prescribed, the furnace must be set at 495 ± 5 deg. C., this temperature to be evenly maintained in all parts of the furnace and throughout the solution heat-treatment process, taking usually from 2 to 4 hours. Only electrically-heated furnaces with air circulation and automatic heat control can fully satisfy these requirements. Air circulation is essential in any case, because the rate of heating would be two or three times slower without it.

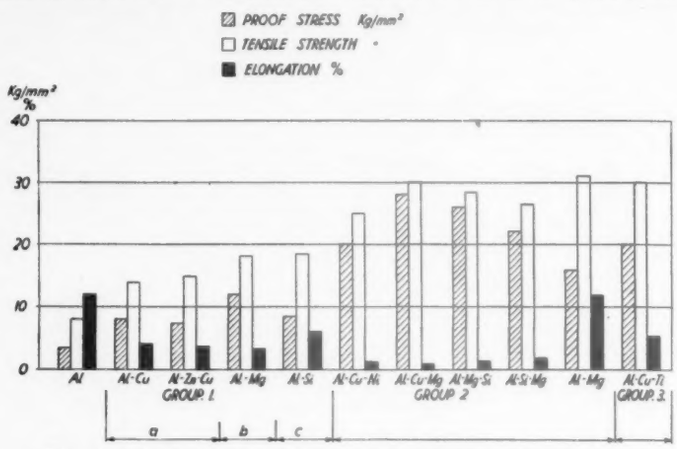

FIG. 1.—TECHNOLOGICAL GROUPS OF ALUMINIUM CASTING ALLOYS (SAND-CAST).

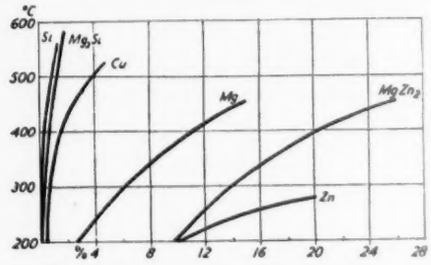

FIG. 2.—SOLUBILITY OF HARDENERS IN ALUMINIUM.

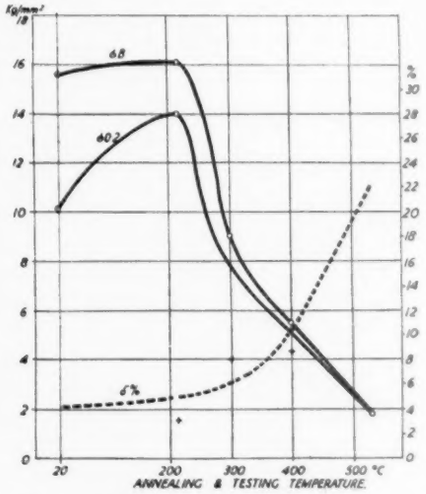

FIG. 4.—MECHANICAL PROPERTIES OF "ANTICORODAL" (CHILL-CAST), TESTED AT ELEVATED TEMPERATURES.

Two pit furnaces separated by the quenching tank may be used. One of the furnaces is used for solution heat-treatment and the other for the precipitation heat-treatment. The heating elements are fixed in the brickwork or on the cylindrical element of non-scaling steel which separates the furnace chamber from the heating elements. A motor, driving a centrifugal fan, is installed on the cover of the furnace. The hot air is sucked past the heating elements and blown into the furnace chamber through the open element. By means of a thermocouple inserted into the cover, the furnace current is regulated automatically.

The power rating of a furnace for solution heat-treatment having a diameter of 40 in. and

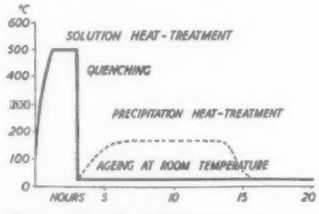

FIG. 3.—HEAT-TREATMENT OF ALUMINIUM ALLOYS SHOWN DIAGRAMMATICALLY.

60 in. deep, is 35 kw. For precipitation heat-treatment about 6 kw. are required for a furnace of the same size.

Apart from the temperature and duration of the solution heat-treatment, the total power consumption, of course, depends also on the size of the castings. Smaller castings are introduced into the furnace in a light charging basket of non-scaling steel by means of a jib crane. Upon completion of the solution heat-treatment the basket with the castings in it is dipped into the quenching tank.

Large castings are hung on to chains so that no basket is used. As the strength of aluminium alloys is greatly reduced at solution heat-treatment temperature, the castings may occasionally be deformed on account of their own weight. Where this risk exists, the casting must be protected from deformation by means of special steel supports. Fig. 4 shows the reduced strength of an Al-Mg-Si alloy (Anticorodal) at elevated temperatures.

When a charging basket is used, the electric power consumption for each pound of castings

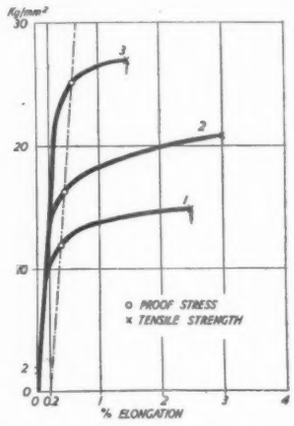

FIG. 5. — STRESS-ELONGATION DIAGRAM OF "ANTICORODAL" (SAND-CAST): (1) AS CAST; (2) SOLUTION HEAT-TREATED AND AGED AT ROOM TEMPERATURE; (3) SOLUTION HEAT-TREATED AND AGED AT 160 DEG. C.

is, of course, higher, because the basket is heated with the casting and often weighs more than the charge. For castings of 25 to 50 lbs., the power consumed by a solution heat-treatment of 3 hours at about 530 deg. C. and a subsequent precipitation heat-treatment of 12 hours at 160 deg. amounts to about 0.25 to 0.7 kw.-hr./lb., the lower figure pertaining to heat-treatment without the basket and the higher to heat-treatment with the basket.

In order to make the fullest possible use of the solution heat-treatment furnace, several precipitation heat-treatment furnaces should be provided for each solution heat-treatment furnace, their number depending on the relative duration of the two processes.

In order to avoid internal strains, distortions

TYPE	NAME	SOLUTION HEAT TREATMENT Hrs.	SOLUTION HEAT TREATMENT TEMP. °C	PRECIPITATION HEAT TREATMENT Hrs.	PRECIPITATION HEAT TREATMENT TEMP. °C	PROOF STRESS, TENSILE STRENGTH 0 10 20 30 Kg/mm²	ELONGATION 0 2 4 6 8 10 12 14 HARDNESS Kg/mm² 0 20 40 60 80 100 120 140
Al-Cu	Alufont 2	–	–	–	–		
"	"	2-4	480-500	–	–		
"	"	2-4	480-500	6-8	155-160		
"	Alufont 3	–	–	–	–		
"	"	3-6	520-530	10-14	135-140		
"	RR 53	–	–	–	–		
"	"	2-3	525-535	10-20	170-175		
"	Y ALLOY	–	–	–	–		
"	"	1-2	510-520	QUENCHED IN WATER AT 100°C			
Al-Mg	Peraluman 10	–	–	–	–		
"	"	2-4	430-450	10-20	155-160		
Al-Si-Mg	Silumin β	–	–	–	–		
"	" B	3-4	525-535	20	150		
Al-Mg-Si	Anticorodal	–	–	–	–		
"	"	2-4	510-540*	–	–		
"	"	2-4	510-540*	6-12	155-160		

* AS REGARDING TO Si CONTENTS

FIG. 6.—SOLUTION HEAT-TREATMENT AND MECHANICAL PROPERTIES OF ALUMINIUM CASTING ALLOYS (SAND-CAST).

or even cracks, complicated castings should in some cases be sprinkled vigorously with water until they are cold. Castings made of Al-Si-Mg alloys are quenched. Before treating large castings such as motor casings, it is recommended to machine the faces to be matched in a longitudinal and transverse direction, so that a gauge is obtained for eventual adjustments after the solution heat-treatment—these adjustments to be made immediately after the quenching, i.e., prior to the precipitation heat-treatment. In the case of some alloys no precipitation heat-treatment is applied, as these age at room temperature and reach their maximum strength in about three days.

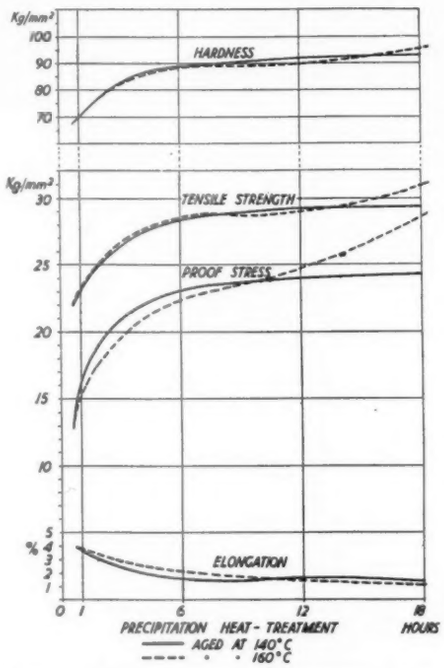

FIG. 7.—MECHANICAL PROPERTIES OF "ALUFONT 2" (SAND-CAST).

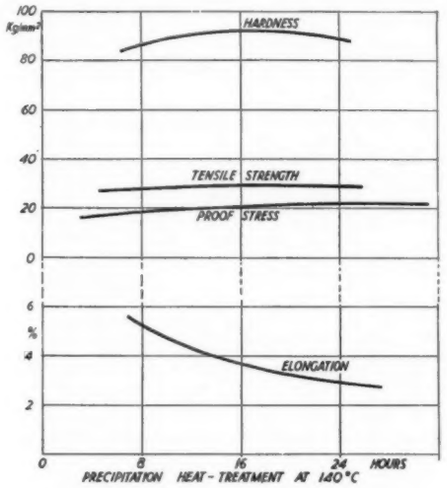

FIG. 8.—MECHANICAL PROPERTIES OF "ALUFONT 3" (SAND-CAST).

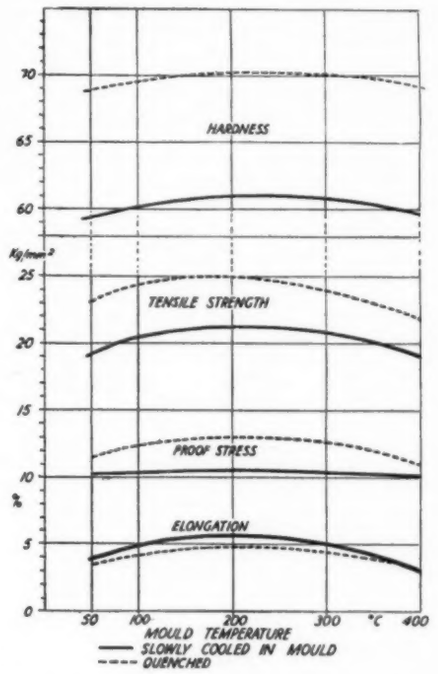

FIG. 9.—INFLUENCE OF RATE OF SOLIDIFICATION ON "ANTICORODAL" (CHILL-CAST).

Effect of Heat-Treatment on Mechanical Properties

Mention has already been made of the effects of the solution heat-treatment temperature. This should be kept as close as possible to the limit of solubility of the hardeners, without exceeding it, however, because this would result in overheating. The duration of the solution heat-treatment also has a considerable effect on the mechanical properties. This effect varies according to the type of casting (whether sand or chill cast) and the composition of the alloy. It should be realised that the term "duration of the solution heat-treatment" includes both the time during which the casting remains at the heat-treatment temperature as well as the period of warming-up. It would not be advisable, for instance, to try to warm a casting in a salt bath to the solution heat-treatment temperature in too short a time. On the contrary, the casting should, as a rule, be warmed-up for over an hour, so that it gradually loses its casting stresses caused by the different speeds at which the various parts of the casting solidify in the mould. Very quick warming-up of the castings may have an effect directly opposite to that of a decrease in stresses, namely, induced stresses and distortions.

The solution heat-treatment generally leads to increased strength, hardness and elongation. While further improving strength and hardness, subsequent precipitation heat-treatment induces a decrease in elongation which varies according to the temperature and duration of the process. This is illustrated by the stress-elongation diagram for Anticorodal shown in Fig. 5. The strength and the elongation of untreated castings (Curve No. 1) are increased by the solution heat-treatment and the quenching (Curve No. 2); a subsequent precipitation heat-treatment lasting 8 to 10 hours at 160 deg. C. causes the strength to increase still further, but the elongation to decrease considerably (Curve No. 3). The precipitation heat-treatment temperature is of utmost importance, as some alloys attain the same strength combined with greater elongation, if a lower temperature of, for instance, 140 deg. C. combined with longer duration is used.

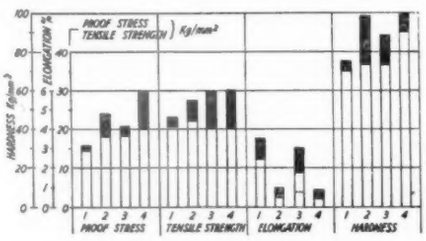

FIG. 10.—INFLUENCE OF HEAT-TREATMENT ON "ANTICORODAL" (PRESSURE DIE-CAST): (1) AS CAST; (2) AGED AT 160 DEG. C.; (3) SOLUTION HEAT-TREATED AND AGED AT ROOM TEMPERATURE; (4) SOLUTION HEAT-TREATED AND AGED AT 160 DEG. C.

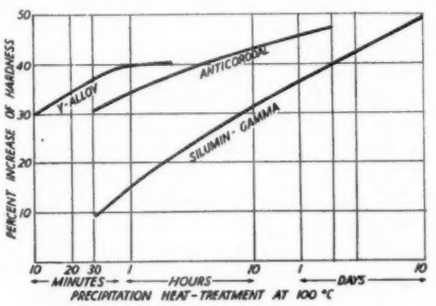

FIG. 11.—INCREASE OF HARDNESS BY PRECIPITATION HEAT-TREATMENT AT 100 DEG. C.

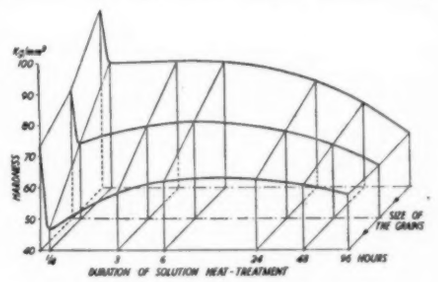

FIG. 12.—EFFECT OF GRAIN SIZE AND DURATION OF SOLUTION HEAT-TREATMENT ON THE HARDNESS OF "Y ALLOY."

As regards the heat-treatable alloys at present used by industry, experience has led to the application of the solution heat-treatment and precipitation heat-treatment temperatures and times shown in Fig. 6, the actual temperatures and periods being so selected as to give the alloy the mechanical properties required by the purpose for which it is used.

"Alufont 2" is an alloy made up of scrap from the Al-Cu-Mg forging alloy and 4 per cent. Cu, 2 per cent. Si, 0.5 per cent. Mn, 0.2 per cent. Mg, and 0.2 per cent. Ti. As shown in Fig. 7, a solution heat-treatment greatly improves its mechanical strength, which is further enhanced by precipitation heat-treatment at 140 deg. C. or still better at 160 deg. C., but the latter treatment causes a substantial decrease in the elongation. The loss in elongation is much smaller for "Alufont 3," an Al-Cu alloy which contains 4.5 per cent. Cu but only negligible Fe and Si impurities (each under 0.2 per cent.), and has a very fine structure due to the addition of about 0.2 per cent. Ti. Although sand-cast test-pieces of this alloy reach a high tensile strength and elongation (Fig. 8) by means of this treatment, their proof stress is far lower than that of the previously mentioned "Alufont 2." "Alufont 3," therefore, is particularly suitable when high plasticity is required—a property which is not possessed by most other heat-treated casting alloys.

The heat-treatable Al-Mg alloys with about 10 per cent. Mg have also recently gained in importance, especially because it has been made possible to simplify the technique of sand casting —which was complicated by the necessity of adding substances forming a protective gas to

the moulding sand—by means of adding very small quantities of beryllium (French invention). The beryllium added to the metal makes the addition of substances forming a protective gas unnecessary.

Castings made of the Al-Si-Mg alloy "Silumin" also have their tensile strength and their proof stress increased while their elongation is reduced, when they undergo a solution heat-treatment followed by a precipitation heat-treatment. The same hardening effect caused by the precipitation of Mg_2Si is also noticeable with the Al-Mg-Si alloy "Anticorodal," which was discovered before the Al-Si-Mg alloys came into use. The solution heat-treatment followed by ageing at room temperature or by precipitation heat-treatment is also applicable to the Al-Si-Mg alloys.

Influence of Casting Conditions on the Result of the Solution Heat-Treatment

The rate of solidification in the mould affects the mechanical properties of the "as-cast" alloy. This rate can be varied within large limits, especially in the case of chill castings, but actually it depends mainly on the casting properties of the alloy and on the form of the castings. If the mould has a rather low temperature, a rapid solidification should cause the strength to be increased, whilst most of the hardeners (for instance, Mg_2Si) remain in solution and re-precipitate by ageing. Test-pieces

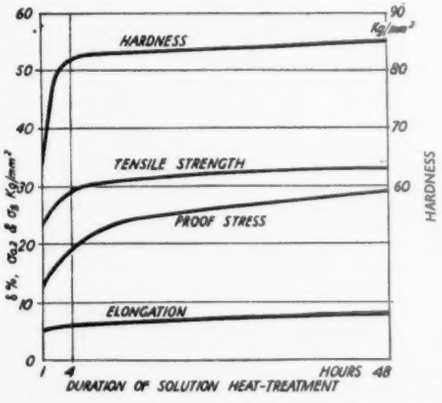

FIG. 13.—MECHANICAL PROPERTIES OF "ALUFONT 3" (SAND-CAST) AS RELATED TO DURATION OF SOLUTION HEAT-TREATMENT.

made of "Anticorodal" at a casting temperature of 700 deg. C. and at mould temperatures of from 50, 200 and 400 deg. C. show practically no difference in strength after 5 days of ageing at room temperature, no matter whether the casting was effected in hot or cold moulds. However, different results are obtained if the samples are quenched at temperatures of from 200 to 300 deg. C. The various conditions are shown in Fig. 9. This simplified hardening method can be applied solely to chill casting, and even then only if the casting has a rather simple form.

In the case of a very high speed of solidification, as in the case of pressure die-castings, the solution heat-treatment has only a slight effect, and a precipitation heat-treatment is sufficient in most cases. It is, indeed, to be preferred to a solution heat-treatment followed by quenching, as it does not cause the thin pressure die-castings to become so easily deformed. So far as "Anticorodal" is concerned, this is illustrated in Fig. 10.

If the casting be allowed to cool down slowly in the mould, an ageing and an increase of hardness can take place in the mould itself, and especially so in the case of alloys which respond more easily to precipitation heat-treatment, such as "Y alloy." The differences in strength which are present in practically every casting are almost completely removed by a solution heat-treatment followed by quenching.

Different speeds of ageing are also noticeable in the case of precipitation heat-treatment. When a solution heat-treatment has first taken place, a precipitation heat-treatment at 100 deg. C. endows maximum strength to the "Y alloy" in less than 1 hour, whereas for "Silumin" the maximum strength is not even attained after 10 days, and for "Anticorodal" after about two days, as is shown in Fig. 11.

On account of these lower speeds, the precipitation heat-treatment must take place at a higher temperature for "Silumin Gamma" and "Anticorodal," and the duration of the treatment has to be increased.

The type of structure of the alloy in its "as-cast" state is the deciding factor for obtaining the optimum mechanical properties by means of solution heat-treatment. Liquation and coarseness of grain make it more difficult for the hardeners to go into solution. Likewise, longer times are required for the heat-treatments in order to obtain a state of complete solution. In the case of solution heat-treatment, the size of the grains may be increased also owing to recrystallisation, particularly if stresses caused by the speed of solidification have remained in the castings. This explains why, for certain sizes of grains, a solution heat-treatment causes the mechanical properties initially to decrease, and to increase again only after a rather prolonged period, as is shown in Fig. 12, which has reference to the hardness of "Y alloy."

This diminution in hardness is greater for coarse-grained castings; for fine-grained ones, it is smaller because a shorter solution heat-treatment, of a quarter of an hour, for instance, is sufficient for bringing into solution a fair amount of the hardeners, whereby the diminution in hardness is somewhat compensated. For coarse-grained castings a longer period is necessary until the maximum hardness is reached.

The above examples show that for fine-grained castings, shorter solution heat-treatments are required and a greater increase of mechanical properties is obtained. Furthermore, the speed of ageing at room temperature or elevated temperature is higher for fine-grained castings.

In actual practice, a middle course must be taken, as each casting, whether sand or chill cast, is composed of grains of any size. Fig. 13 shows an example in which a longer solution heat-treatment has brought about a considerable improvement in the mechanical properties of a sand casting of "Alufont 3" alloy containing 4.5 per cent. Cu and 0.2 per cent. Ti.

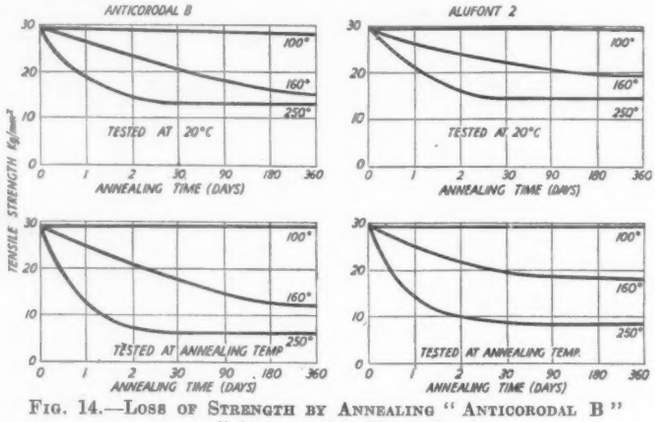

FIG. 14.—LOSS OF STRENGTH BY ANNEALING "ANTICORODAL B" AND "ALUFONT 2" (CHILL-CAST).

Loss of Strength of Heat-Treated Alloys due to Annealing at Elevated Temperatures

With the exception of piston alloys, castings are not usually subjected to elevated temperatures. It should not be forgotten, however, that a long period of annealing at less than 200 deg. C. is sufficient to reduce substantially the highest mechanical properties obtained by solution heat-treatment. At elevated temperatures and after annealing, the heat-treated alloys, containing copper retain their mechanical properties for a longer period than some others. For "Anticorodal" (Al-Mg-Si), for instance, the loss of strength is smaller than for "Alufont 2," as is shown in Fig. 14.

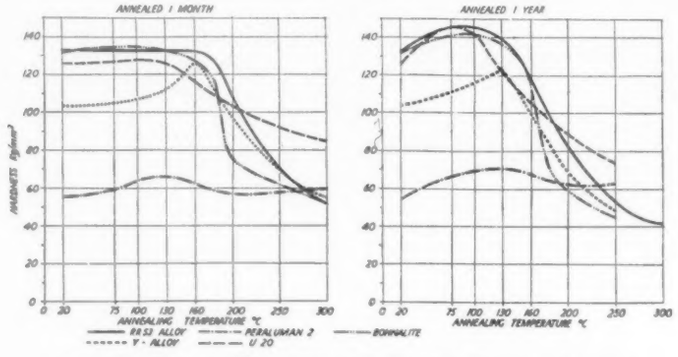

FIG. 15.—LOSS OF HARDNESS OF ALUMINIUM CASTING ALLOYS (CHILL-CAST) AFTER ANNEALING FOR ONE MONTH AND FOR ONE YEAR.

The duration of annealing is of utmost importance; therefore, this should always be indicated when figures on heat resistance are quoted. Typical of alloys with a high heat-resistance are the piston alloys.

Classical amongst alloys is the "Y alloy," whilst the "RR" alloys, which are variations of the former, possess better casting qualities. The piston alloys with copper contents of over

10 per cent., such as "Bohnalite" and "U 20" are another type of heat-resisting alloy. All these alloys are heat-treated. After having been annealed for one month, castings tested at room temperature show that no reduction of hardness takes place before they are heated to temperatures in excess of 160 deg. C. This applies to all the alloys with exception of "Y alloy," which, on the contrary, attains increased hardness due to a precipitation phenomenon (see Fig. 15). At higher temperatures there are only slight differences in hardness between the "Y," "RR 53" and "Bohnalite" alloys, and only the "U 20" alloy is harder.

After annealing at elevated temperatures during a year and testing at room temperature, these differences in hardness continue, though to a lesser extent, and this is shown in Fig. 15.

At lower temperatures, on the contrary, a marked increase of hardness caused by precipitation phenomena takes place also in the "RR 53," the "U 20" and "Bohnalite," for which the precipitation hardening speed is slower than for "Y alloy." By comparing the hardness curves of "Peraluman 2" (Al-Mg) it could be inferred that such an alloy, which is not suited for solution heat-treatment, would be just as good as the heat-resisting piston alloys, in so far as exposure to heat over a long period is concerned, especially at high temperatures.

This may be the case as regards hardness, but respecting the continuous static stress, comparison is rather in favour of the piston alloys, that is, if the creep limits were taken into account. Anyhow, the curves show that it is useless in some cases to exaggerate the initial hardness by means of solution heat-treatment followed by precipitation heat-treatment, as this would make the alloys unnecessarily brittle. However, a precipitation heat-treatment following upon the solution heat-treatment is required in order that the expansion of the metal takes place before the pistons are machined and assembled.

Conclusion

In the present Paper an endeavour has been made to give a brief survey of the heat-treatment processes for casting alloys. These may be briefly summarised as follows:—

(1) The furnaces required for the solution heat-treatment should make it possible to obtain a long duration of the solution heat-treatment and of the precipitation heat-treatment together with great accuracy in temperature.

(2) The mechanical properties obtained are dependent on the rate of solidification within the casting and on the duration of the solution and precipitation heat-treatments.

(3) The high mechanical properties obtained by heat-treatments may be lost if the castings are exposed to elevated temperatures during a long period.

PRESSURE DIE-CASTING IN ALUMINIUM- AND ZINC-BASE ALLOYS

LIMITATIONS AND POSSIBILITIES OF THE PROCESS

By ARTHUR STREET,* B.Sc., Ph.D.

During the past twenty years, pressure die-casting has emerged from the status of a metallurgical curiosity to an industry whose presence makes itself felt wherever bulk quantities of metal parts are involved. The reasons why pressure die-castings are so widely used may be summarised as follow:—

(1) Once the die has been made, production speed is high. Certain automatic die-casting machines have achieved an output of over 1,500 shots per hour; this is exceptional, but a speed of 600 shots per hour can be attained with small die-castings. Automatic machines only show their true advantages when large quantities of fairly small components are involved. For complicated or large parts, and in most cases where the quantities are less than 50,000, fully automatic machines are not often used, but ordinary pressure die-casting machines requiring the full-time supervision of a semi-skilled operator are employed. These, however, attain quite reasonable speeds of production. For example, a zinc-base alloy pressure die-casting, weighing 2½ ozs., with two concentric threads and with a brass bush cast in as insert, attains a production speed of 200 shots per hour. An aluminium-silicon alloy electric-motor body, weighing 1 lb., gives 75 shots per hour. A large and complicated washing-machine gear-case in zinc-base alloy, weighing 14 lbs., averages 18 shots per hour.

(2) It is possible to produce what is either the finished article or a close approach to it. Holes, threads, lettering and decorative features can be produced, and the design of the part is only limited by the desirability of opening and closing the die with the minimum of trouble. Fig. 1 shows a group of pressure die-castings in aluminium- and zinc-base alloys, representing a type of design which specially lends itself to the process. The parts were cast on to the top of the dome portions with the moving die-block coring the domed recesses in each case. These die-castings range in weight from less than 4 ozs. to 7 lbs.

(3) The pressure die-casting is accurate to ± 0.001 to 0.002 inch per in. Particularly in the zinc-base alloys holes can be cast with a taper of only 0.002 inch per in.; in aluminium alloys where the molten metal "drags" on the steel cores, the necessary draught is higher, being about 0.015 inch per in. (the exact figures depend on conditions).

(4) Mainly on account of the high pressure of injection, the surface appearance of a pressure die-casting is so good that often it can be used in the "as-cast" state, and in any case, if a finish is necessary, its cost is reduced to a minimum.

(5) On account of the rapid chilling, the strength and hardness of a pressure die-casting will be superior to those of the same alloy in the sand-cast state. For example, a zinc-base alloy sand-cast gives a tensile strength of 7 to 9 tons per sq. in.; in its gravity die-cast form the alloy has a strength of about 14 tons, while in the pressure die-cast condition the alloy will have a tensile strength of 18 to 21 tons per sq. in.

FIG. 1.—PRESSURE DIE-CASTINGS IN ALUMINIUM- AND ZINC-BASE ALLOYS.

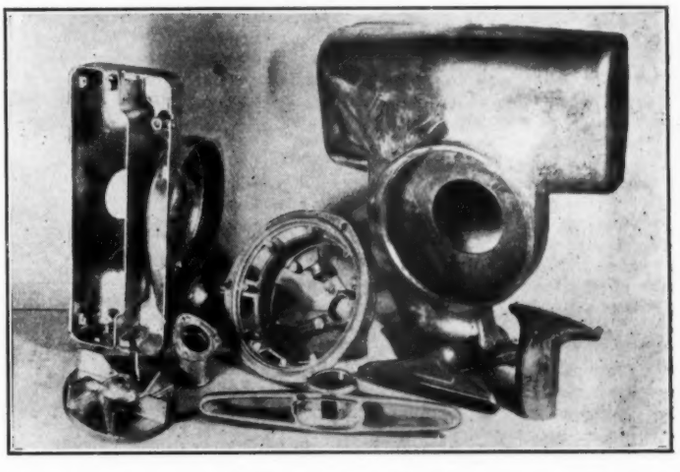

FIG. 2.—ALUMINIUM-ALLOY PRESSURE DIE-CASTINGS FOR VACUUM-CLEANER COMPONENTS.

Examples from Industry

Because of the possibilities which pressure die-casting opens up, it has enabled a number of modern amenities to develop, which would certainly be less efficient and more expensive if there had been no such thing as pressure die-casting. Fig. 2 shows a group of vacuum-cleaner parts, pressure-cast in aluminium alloy, and indicates that this industry owes much to the use of die-castings. The motor-vehicle industry is one of the largest consumers of pressure die-castings, particularly in the zinc-base alloys, and

* Fry's Diecastings, Limited, Birmingham.

many important features, such as carburettors, petrol pumps, electrical equipment, and door and window operating gear have been immensely cheapened and improved by the use of these die-castings.

Fig. 3 illustrates the well-known Rawlplug mechanical hammer, in its original state (lower half), and after an aluminium-silicon alloy pressure die-cast body had been used (upper half). The manufacturers report that they have used over 22,000 die-cast cases, and they say that the amount of machining has been reduced almost to zero. There are no rivets or screws to work loose, and it is possible to use longer and more robust bearings, as they can be "cast-in." The hammer case being made of a pair of die-castings makes assembly easy; all parts drop readily into accurately cored holes. The design is so adjusted to give strength combined with lightness—an important feature with portable tools which are subjected to much abuse. The excellent appearance of the pressure die-cast case is an added advantage.

(*Courtesy Rawlplug, Limited.*)

FIG. 3.—"MECHANICAL HAMMER" BEFORE AND AFTER IT WAS DIE-CAST.

Competition with Other Processes

In view of the rapid development of the pressure die-casting process it occurred to the writer that members of the foundry industry might hold strong opinions on the rise of this youthful competitor. Several Midland members of the Institute of British Foundrymen were therefore consulted on the subject of "Die-casting *versus* Sand casting." Their replies have been most illuminating and are embodied in the present Paper.

The spokesman of a large firm of casters in the Midlands stated that in recent years they have certainly lost orders to the die-casting industry, although the inroads of die-castings against their light grey-iron foundry business were said not to have been really severe. The other gentlemen who have been approached were not of the opinion that the industry was throwing foundrymen out of work and, indeed, in several cases it was suggested that die-casting has been a stimulus to its "elder brother." For instance, the foundry manager of a large firm making weighing machines reports that although they had been using very many die-cast parts for the last 15 years, the production in their grey-iron foundry had increased by about 100 per cent. over the same period.

It seems obvious that the main reason why die-casting does not interfere with the ordinary foundry is that the process works within a number of definite limitations, which have meant that die-casting has only been employed in the manufacture of certain classes of articles in a few well-defined alloys. In recent years so much has been said about the undoubted advantages of die-casting that it might be a useful change to consider the limitations of the process which explain why die-casting has been able to exist and thrive without deleterious effects on the ordinary foundry. It must be stressed that the present Paper deals essentially with pressure die-casting.

Limitation of Alloy

The conditions under which the die-casting is made are so severe that only certain alloys are ideal for the process. Over 80 per cent. of the pressure-cast tonnage in this country is made up of:—

(1) The zinc-base alloys (with aluminium 4.1 per cent., copper 0 to 2.7 per cent., magnesium 0.03 per cent.; balance zinc of "99.99 plus per cent." purity).

(2) Aluminium alloy of L.33 composition, with silicon 11 to 13 per cent.; occasionally copper up to 0.5 per cent. is added.

(3) A small percentage of aluminium alloy with copper 4 to 5 per cent. and silicon 2 to 3 per cent.

(4) A still smaller percentage of L.8 and miscellaneous alloys.

The list of alloys which are not considered to be commercially "pressure die-castable" include a large number of compositions which are not widely die-cast at present but which possibly could be adapted to the process if the need were very urgent. Thus gunmetal and pure 70/30 brass could be pressure-cast if the mould and the die-casting machine were specially adapted to the purpose. It might be mentioned here that improvements are being brought about in the die-casting of high melting-point alloys, for instance, cast iron and nickel alloys.

At the same time, it is a fact that certain alloys (for instance L.33 and the zinc-base alloys) pressure die-cast excellently, while other compositions (for instance, L.5, which is hot-short) are not suitable. The writer would not attempt to say definitely what makes an alloy "pressure die-castable," because there are so many variable factors, but in the hope that this question will one day be settled, the various factors are briefly discussed below.

Effect of Melting Point

The life of the die is not a direct inverse function of the melting point, but an exaggerated one; thus the life of a part of a tool for zinc-alloy die-castings would be at least four times that of a part of the die producing an aluminium-alloy pressure die-casting. The problem of the effect of high melting-point alloys on the die steel which is available has caused the process to become specially associated with alloys of low and medium melting-point.

In connection with the subject of die-life, which is so important in deciding whether an alloy is suitable for die-casting, it must be mentioned that a die does not "expire suddenly" but deteriorates in stages. For instance, in the case of an aluminium-alloy pressure die-casting, it is likely that after about 20,000 shots, core pins of small diameter may show signs of necking, and may have to be renewed. Then, at about the same time, the surface of the tool may develop hair-cracks which will be reproduced on the face of the die-casting. If appearance be vital, the tool may have to be sent back for removal of these surface blemishes.

Only if the steel is quite inadequate or if the workmanship is bad does a die have to be renewed entirely. For example, careful questioning in the toolroom of Fry's Diecastings, Limited, revealed that in the last four or five years only one pressure die has had to be completely re-made, and then it had produced 60,000 aluminium-alloy parts, and the toolroom foreman was of the opinion that this particular die had been "badly made."

TABLE I.—*Effect of the Freezing Range of Various Die-casting Alloys on General Suitability.*

Alloy.	Liquidus.	Solidus.	Freezing range.	Notes.
	Deg. C.	Deg. C.	Deg. C.	
10 per cent. alum. bronze ..	1,043	1,038	5	Gravity die-casts excellently, but difficult for pressure die-casting.
Gunmetal	1,000	845	155	Can be die-cast with difficulty using special plant and low pressures. Not usually employed.
90/10 tin bronze	970	815	155	Not commercially pressure die-cast.
70/30 brass	950	920	30	If of commercial quality and therefore hot-short, cannot be pressure-cast.
60/40 brass	904	900	4	Pressure-casts well.
L.5	610	490	120	Not suitable for pressure die-casting.
L.8	622	545	77	More suitable for gravity casting than the pressure process.
L.11	630	540	90	More suitable for gravity casting than the pressure process.
L.33	600	577	23	Pressure die-casts excellently.

Effect of Freezing Range of the Alloy

It seems distinctly possible that this is an important factor, and that a long freezing range means that the alloy will be difficult to pressure-cast and achieve solidity. Table I gives par-

ticulars of copper and aluminium-base alloys which are popular and unpopular with pressure die-casters. Speaking broadly, it will be seen that in each class the popular pressure die-casting alloys are those with the shortest freezing range. Aluminium-bronze is purposely put in as an exception; other factors interfere and make the alloy quite difficult to pressure-cast (for instance, high melting-point, high contraction, and tendency to form aluminium oxide in the turbulent pressure die-cast state). No doubt the reason why alloys with long freezing range are generally difficult to pressure-cast is that the first solidified metal bridges across the section encircling localities of still-solidifying alloy which is thus prevented from being fed.

Effect of Contraction

Although the cores are withdrawn from the die-casting almost as soon as its outside skin has become solid, these features of the die impose a restraint on the free contraction of the alloy. In an endeavour to get maximum production and finest grain-size, moulds are frequently water-cooled, and under these conditions the die-cast alloy falls very rapidly in temperature; thus some works experiments indicated that the first 200 deg. C. of cooling of an aluminium-alloy die-casting took place in under one second. The higher the contraction figure, the higher the stress that will be set up in the constrained die-casting. However, the contraction *per se* is not an essential factor, but is linked up with strength and ductility at high temperatures.

TABLE II.—*Mechanical and Physical Properties of Four Alloys.*

BRONZE.—86.5 per cent. copper, 11.9 per cent. tin, 1.3 per cent. zinc.
Total linear contraction, 1.5 per cent.
Not commercially die-castable.

Temp. Deg. C.	Tensile strength. Lbs./sq. in.	Elong. Per cent. in 2 in.
20	42,200	16.5
230	40,800	15.0
290	34,800	12.0
345	26,200	4.0
425	20,400	2.0

BRASS.—62.4 per cent. copper, 37.6 per cent. zinc.
Total linear contraction, 1.8 per cent.
Pressure die-casts satisfactorily.

25	61,000	27.0
250	53,700	20.0
390	20,900	41.0
500	7,500	43.0
550	5,800	32.0
630	2,800	27.0

ALUMINIUM-SILICON ALLOY.—With 12 per cent. silicon.
Total linear contraction, 1.3 per cent.
Pressure die-casts excellently.

25	26,500	8.0
100	23,850	10.5
150	19,050	12.8
200	14,300	13.0
250	11,000	14.8
300	7,850	15.0
375	5,050	21.5

ALUMINIUM-COPPER ALLOY.—With 8 per cent. copper.
Total linear contraction, 1.2 per cent.
Not suitable for pressure die-casting intricate jobs.

25	21,700	1.0
100	21,100	1.0
150	19,750	2.0
200	17,500	1.0
250	16,250	1.0
300	11,000	2.5
375	5,650	11.8

Strength and Ductility at High Temperatures

If a die-casting is solidifying against the restraint of the die, it will temporarily be prevented from contracting to its fullest extent. Assume that if a part could have contracted freely, it would have shrunk by X per cent. If some part of the die constrains that metal from shrinking, a stress Y will be set up. If the metal at a temperature of, say, 300 deg. C. below its melting-point is hot-short, it will only have a low elongation figure at that temperature, and if the elongation figure be less than X, a stress greater than Y will be set up, and consequently the metal will crack. Additionally, it must be remembered that because of the very rapid chilling it will be a suddenly applied and therefore augmented stress which will be set up. Table II gives particulars of the tensile strength and elongation of four alloys, together with their contraction figures and a note as to their "die-castability." The existence of the other factors which affect "die-castability" prevents definite conclusions from being drawn from these figures, but it will certainly be noted that the two alloys which do not appear to pressure die-cast so well pass through a stage in freezing when their elongation is so low as to approach the figure for linear contraction.

Solution Effect of the Liquid Metal on the Mould

If a metal or alloy tends to dissolve iron, it will not be suitable for die-casting on account of its solution effect on the die. Thus unalloyed zinc, although it can be die-cast, provided the metal is of extreme purity, is not commercially suitable because the zinc galvanises the mould. If 0.03 per cent. of aluminium is added, the solvent tendency is reduced to one-quarter. When 4 per cent. of aluminium is present, as in all modern zinc-base die-castings, iron solution is completely inhibited.

When the author first commenced to think about the "die-castability" of various alloys, it was hoped that some definite factor would be found which would decide whether or not an alloy was suitable. As a result of the discussion above it will probably be agreed that some properties make pressure die-casting difficult, but it is likely that there are few alloys which would be quite impossible to die-cast, providing attention was given to the design of the die and the machine, and the operators were given time to get experience in making die-castings in the specific alloy. This human element factor is a very real one; the author remembers that a good many years ago when zinc of 99.99 per cent. purity was first used for zinc-base die-castings, the workmen stated most volubly that the stuff was quite impossible to die-cast, yet after a few weeks' experience with the new alloys they soon mastered the problem. Again quite recently, some of the same men were asked to make castings in one of the original zinc-base alloys containing aluminium, copper and tin, such as were widely die-cast 15 years ago. This time the operators declared that the tin-containing alloy was quite impossible to die-cast!

Weight and Size of Die-Castings

Sand castings can be made many yards long and many tons in weight, but die-castings are chiefly limited to the light-castings field. The largest pressure die-castings which have been produced have been not much more than 30 lbs. in weight. The difficulty of making a bulky pressure-casting does not only consist in constructing and handling a die, which may weigh more than 4 tons, but, what is still more difficult, provision has to be made for exerting holding pressures, which may run into hundreds of tons, to resist the bursting effect of the incoming metal. The tendency for the components of the die to spring must be avoided both from the point of view of safety and the need for maintaining accurate dimensions. The problem of filling the large die has also to be considered; if the metal temperature is raised to improve fluidity, unsoundness may result, both at the extremities of the mould and in the vicinity of the runner.

However, while a pressure die-casting is limited with regard to the production of bulky components, it must be admitted that it is ideally suitable for making small parts. The individual components of a zip fastener have been produced by this method and watch parts, weighing 1/200th of an ounce, have been pressure die-cast.

Solidity of Pressure Die-Castings

One of the foundry managers who replied to the author's *questionnaire* raised an interesting point by asserting that "where soundness is of great importance (*e.g.*, petrol or oil proof), die-castings generally are inferior to sand castings." This raised the controversial question of the soundness or otherwise of pressure die-castings.

In the first place it must be realised that, from the solidity point of view, the die-caster faces different problems from the ordinary founder. The latter is beset by a multitude of trials and tribulations which make it a source of admiration that solidity is so regularly achieved; but apart from minor evils, a sand casting may develop unsoundness from any of three causes—blowholes due to gas evolution, air-locks and shrinkage cavities. The foundryman overcomes the three forms of unsoundness by providing risers, vents and chills wherever necessary and by blending the sand to make it porous or impermeable as is required at any point.

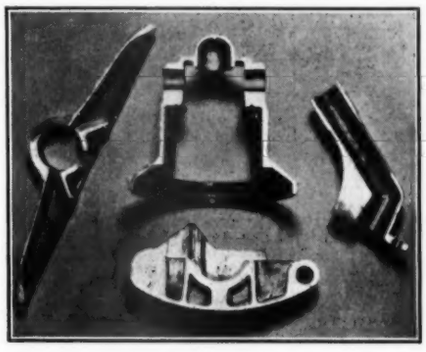

FIG. 4.—SECTIONED ALUMINIUM-ALLOY PRESSURE DIE-CASTINGS.

The evolution of gases is not serious from the die-caster's point of view. For one thing the high pressure at which the metal is cast tends to keep gas in solution and, secondly, the die-casting is generally cast as near the melting point as possible and not 50 or more deg. C. above it as in foundry work.

Although shrinkage cavities are sometimes troublesome in gravity die-castings, only a badly-made pressure die-casting suffers from them, as the feeding effect of the continued application of pressure should in a suitable alloy prevent insufficient filling of the mould. However, entrapped air can be distinctly troublesome. The metal enters in a turbulent condition and is intimately mixed with the air which was previously contained in the mould and runner. Particularly where the metal has to be run on the side of a circular impression or where the section changes abruptly, it becomes difficult to get rid of air during the fraction of a second in which the die-casting solidifies.

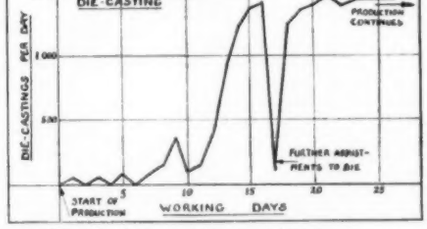

FIG. 5.—DAILY OUTPUT FIGURES OF A PRESSURE DIE-CASTING.

Risers and very liberal vents are out of the question and the steel mould cannot be made gas-permeable. The die-caster endeavours to liberate

entrapped air by venting (*a*) along the parting line; (*b*) up the narrow orifices which represent core pin clearance, and (*c*) by cutting sumps in the die, attached to the die-casting impression by a thin channel. Entrapped air and oxide are forced into these "sumps" which are subsequently clipped away. High pressure of injection is useful in preventing unsoundness but alone it is not sufficient. The construction and venting of a tool are the real key as to whether or not the pressure die-casting will be solid. As illustration of the kind of results which are obtained, Fig. 4 shows some sectioned pressure-castings all in aluminium alloy. It will be seen that the only part which has been at all troublesome is the wide section in the lower die-casting.

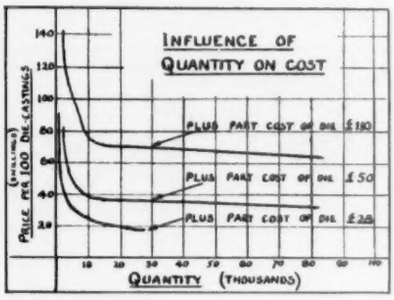
INFLUENCE OF
QUANTITY ON COST
PRICE PER 100 DIE-CASTINGS (SHILLINGS)
PLUS PART COST OF DIE £10
PLUS PART COST OF DIE £5 0
PLUS PART COST OF DIE £2 0
QUANTITY (THOUSANDS)

FIG. 6.—INFLUENCE OF QUANTITY ON COST.

The Economic Factor

It is nowadays realised that pressure die-casting is not really suitable for the manufacture of quantities less than 5,000 per annum. Not only has an elaborate die to be made, but the production speed varies considerably with increasing experience. It is quite usual for only a few score of die-castings to be produced in the early days of production, whilst when the tool is running smoothly and the operator is accustomed to the idiosyncrasies of that particular job, the production speed may rise to several thousand shots per day. Fig. 5 is a diagram taken from the daily production figures for a medium-sized zinc-base alloy pressure die-casting. This job was more troublesome than most—it contained two cast threads, a thin spigot and a cast-in brass insert, and the diagram illustrates that at least on this particular difficult job the cost of producing the first 1,000 would have been probably ten times the cost of making the tenth thousand.

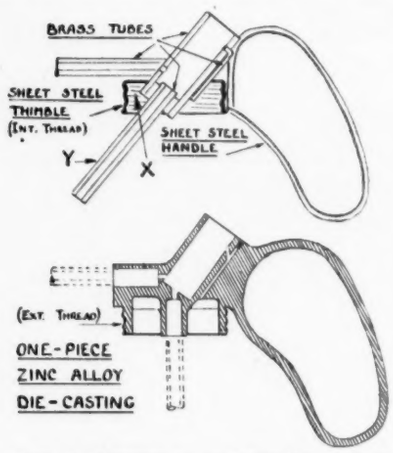

FIG. 7.—DESIGN OF AN OILER TOP BEFORE AND AFTER IT WAS DIE-CAST.

Fig. 6 is based on the cost of three actual zinc-base die-castings, but the estimated cost of different quantities has been worked out to illustrate that quite apart from tool cost the question of numbers has to be seriously considered to decide whether a part is suitable for pressure die-casting.

Limitations of Design in Pressure Die-Casting

It may be assumed that any foundryman worth his salt can produce castings to practically any design in almost any alloy, but the preceding remarks will have indicated that the die-caster is not in the same happy position. Not only is he restricted in the choice of alloy, but, on account of the rigid nature of the permanent steel mould, he is limited in the design of any part which is to be die-cast. Any feature which hinders the opening and closing of the die or which prevents the straight-line withdrawal of cores is either going to make the design impossible to execute or will cause the die-casting to be unduly expensive. The design of any die-casting must be considered on its merits, for very often a difficult feature can be produced in one case, while it would be impossible in another. However, there are certain outstanding limitations which must always be considered.

Simplicity of design must be aimed at to ensure rapidity of production. Awkward corners and recesses are frequently encountered in parts which manufacturers would like to have die-cast, and Fig. 7 indicates how such problems are dealt with. The upper view shows the section of a pressure-feed oilcan top as it was originally—a soldered assembly of pressed and turned parts—and below is shown the one-piece pressure die-casting which replaced it. In the original design a recess at X was formed by the inclined inlet-tube assembly Y, and it will be seen that such a recess would prevent a steel core from being withdrawn. It was found possible (and indeed an improvement) to arrange the inlet tube vertically, as shown in the lower view, and at the same time to die-cast an external thread to suit the rolled thread on the oil container. Further, it was possible to include the handle as part of the die-casting, thus eliminating all soldering operations. Assembly costs were substantially reduced and the strength and efficiency of the article were improved.

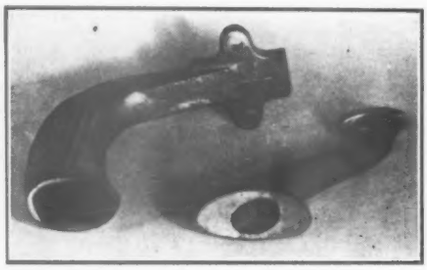

FIG. 8.—PRESSURE DIE-CASTINGS WITH CURVED CORED HOLES.

FIG. 9.—ALUMINIUM-ALLOY PRESSURE DIE-CASTING PRODUCED BY USING A "KNOCK-OUT" CORE.

In order to obtain maximum speed of production, cores should, if possible, be withdrawn in a straight line. The use of collapsing sand cores is quite impracticable owing to the high pressure of injection of the metal, and the "messiness" of letting sand come in contact with a complex steel die. Cored holes, therefore, are limited to shapes which can conveniently be formed by steel cores. Although straight-line holes are preferable, certain irregular shaped holes can be produced in a pressure casting. Fig. 8 shows two components with bent cored holes which have been produced by cores shaped to the arc of a circle which were rocked in and out of position. Pressure die-cast domestic taps which have been produced in brass are well-known examples where a curved hole has been produced by such a movement.

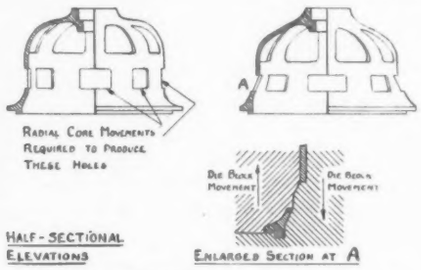

FIG. 10.—PRESSURE-CAST MOTOR BODY, SHOWING MODIFICATION TO VENTILATION SLOTS FOR FACILITATING CORE OPERATION.

Undercuts can be formed by cores which are constructed in several pieces and which are removed by a separate operator after the casting has been taken from the machine. Fig. 9 shows an aluminium-alloy pressure casting in which the recess forms an undercut. Core 1 is withdrawn through the hole at the side while the casting is on the machine. It is then withdrawn, still containing core-blocks 2, 3 and 4, which are subsequently unlocked and removed in this order. In the gravity die-casting process, which may be regarded as a kind of half-way house between pressure die-casting and foundry casting, undercuts of considerable complexity may be achieved by cores which are built up of several sections and which are dismantled piece by piece. Certain motor-vehicle pistons are examples of this. The pressure-casting process, however, is much more limited with regard to undercuts, for the "knock-out" core has to be constructed and fixed to withstand the heavy impact of the incoming metal while at the same time it has to be easy to dismantle.

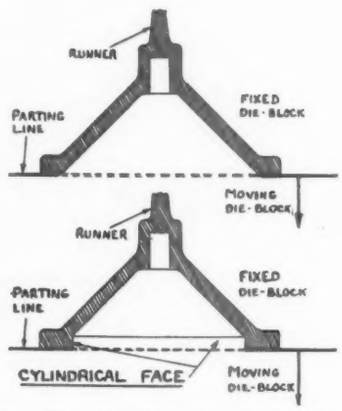

FIG. 11.—ADDITION OF CIRCULAR RING TO FACILITATE WITHDRAWAL IN CORRECT DIRECTION.

Speaking generally, cores must be arranged to withdraw in as few directions as possible;

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usually cores in any one direction are operated together and, except in special cases, every direction of core movement means additional mechanism in the die and increased operations on the machine. Because of this, die-casting designs in their early stages are carefully considered in order to assemble core movements in the minimum number of directions. For example, the electric-motor body illustrated in Fig. 10 was originally designed with radial ventilation holes. These would have involved an expensive tool, and the design was therefore altered so that the slots were cored by the moving die-block as shown on the right-hand side of the illustration.

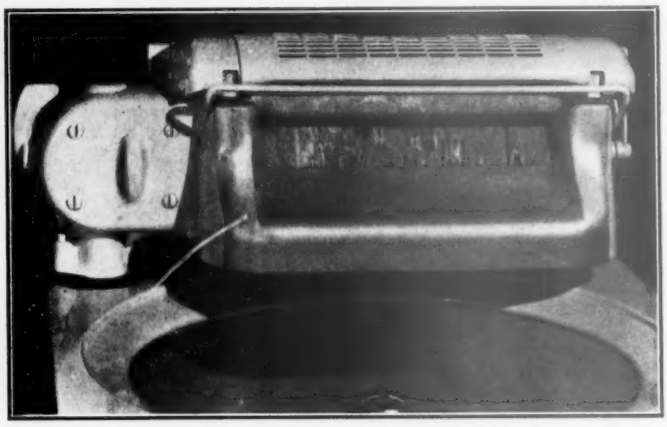
If the die-casting contains a main dome-shaped recess, as in Fig. 10 and also in Fig. 1, such a recess is cored by the moving die-block. Smaller holes in the same plane as the main recess are produced by separate core-pins working in the moving die-block, so that they may be easily renewed without scrapping half the die.

Usually it is found more convenient when the casting is arranged to contract on to the moving die-block from which it is subsequently ejected. If the design were such that the die-casting adhered to *either* die-block as the spirit moved it, the casting cycle would be considerably slowed down, particularly when the die-casting, with the runner attached to it, had to be extricated from that half of the die which was not provided with ejector pins. Very often die-casters will request their customers to provide a taper in a certain direction so that the die-casting shall be forced to withdraw in the desired direction. Fig. 11 shows a simple die-casting where a similar alteration was agreed to. The original design (shown above) would be more likely to adhere to the runner side of the die, but by the addition of a cylindrical face (shown below) the part was made to adhere to the moving die-block.

The design limitations of pressure die-casting are naturally troublesome at times. Many shapes cannot be die-cast if it is found impossible to alter their design to bring them into line with the requirements of the process. Then it is risky to undertake a die-casting if the design of the part is liable to alteration. Such an alteration in a sand casting might only mean the expenditure of a few shillings on the pattern. Sometimes, of course, alterations to a pressure die-casting are reasonably cheap; for instance, if a hole is to be made smaller, the core producing it could conveniently be machined down. On the other hand, if the same hole had to be made *larger*, it would mean making a new steel core, boring out the die and altering the mechanism to accommodate the larger core pin. Many seemingly simple-looking alterations mean the scrapping of half the die because they would necessitate adding metal to the die to form what is wanted.

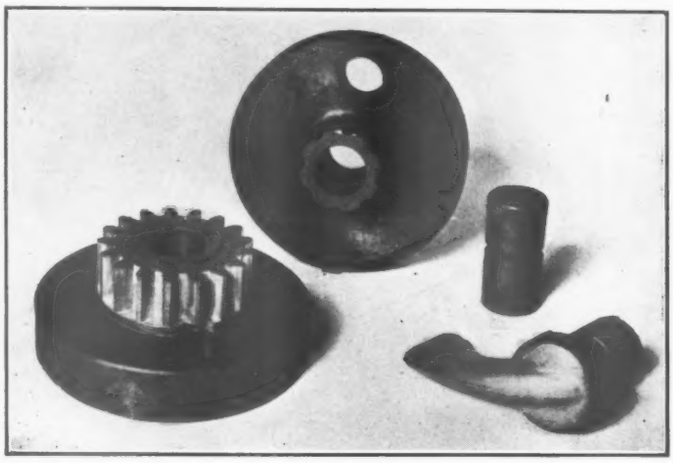
A further point connected with the expensive tooling is that it is difficult and sometimes costly to test new ideas. Even if a sample foundry casting is made its strength will not be equal to that of the pressure die-casting, and so the test would not be a fair one. Unfortunately, this applies in particular to the zinc-base alloys where would-be users almost invariably want to make some sort of test, if they are unfamiliar with these essentially pressure die-casting alloys.

On the other hand it is certain that the "limitations" of pressure die-casting have brought many advantages. Human nature is prone to



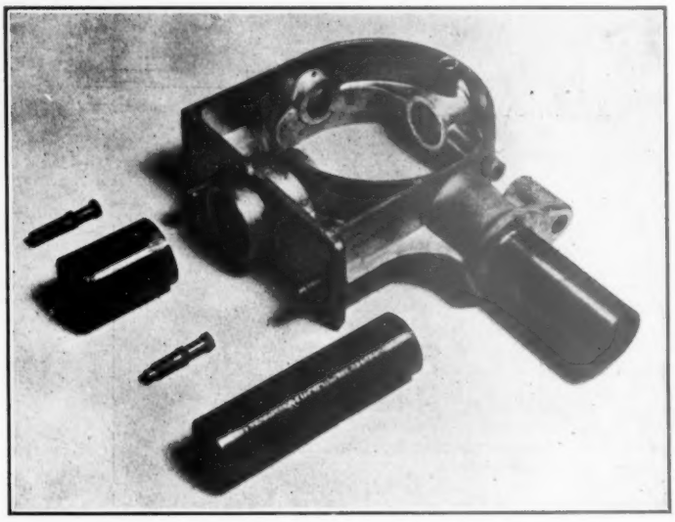
(Courtesy Hotpoint Electric Appliance Co., Ltd.)

FIG. 12.—DOMESTIC ELECTRIC WRINGER, SHOWING PRESSURE-CAST BODY, GEAR-BOX, ETC.



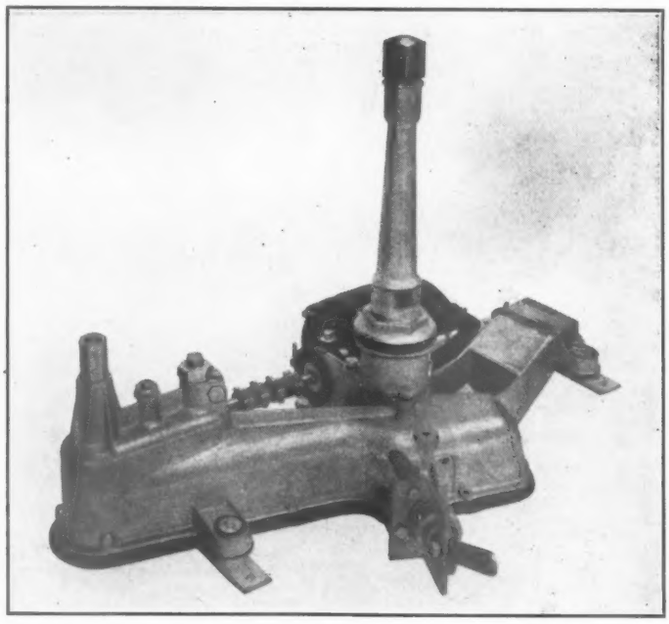
(Courtesy Hotpoint Electric Appliance Co., Ltd.)

FIG. 14.—WRINGER DETAILS WITH LARGE INSERTS.



(Courtesy Hotpoint Electric Appliance Co., Ltd.)

FIG. 13.—WRINGER GEAR-BOX, SHOWING CAST-IN INSERTS.



(Courtesy Hotpoint Electric Appliance Co., Ltd.)

FIG. 15.—WASHING-MACHINE GEAR-CASE ASSEMBLY SHOWING PRESSURE DIE-CAST GEAR-CASE, POST AND GYRATOR POST NUT.

take the line of least resistance, and if a design is possible, users will not have much stimulus to make alteration. If, however, a die-caster tells a potential user that a certain design is quite definitely impossible, the user is very often encouraged to make a fresh start and consider the design from first principles, and in so doing can take the opportunity of simplifying and improving the whole assembly; this has happened on innumerable occasions. As illustrating a modern application of pressure die-casting where considerable care has been put into the design to make the components suitable for this method of production, the well-known Hotpoint electric domestic wringer and washing machine will now be discussed.

Redesigning a Domestic Wringer for Die-Casting

In the original model the wringer was of cast iron; the basic design had been found satisfactory in service, and it was desired that this should be retained, while at the same time making use of the advantages obtainable by the use of die-castings. Although it was realised that modifications would have to be made, the die-cast wringer had to be so planned that its major parts would be interchangeable with those of the original design. For instance, as the machine would give a long service, it was desirable that a new die-cast gear-box could be fitted on to the original design of wringer head and *vice versa*. At the same time as the change-over to pressure die-casting occurred, the opportunity was taken of making other improvements—improved safety mechanism was incorporated, and constant-mesh gears were adopted instead of the sliding-gear type.

With ferrous material there is a possibility of trouble through rusting or corrosion. As the wringer is naturally in contact with alkaline solution and any rust must not be allowed to contact the clothes, a non-ferrous metal was desirable. Additionally it was desired to make a reduction in weight, so aluminium-silicon alloy was chosen to be used wherever possible.

The reduction in weight was a substantial one. The total weight of the appliance was originally 45½ lbs.; in addition to this the safety mechanism introduced in the new model weighed an extra 3 lbs., but thanks to the use of aluminium-alloy pressure castings the total weight was reduced to 34 lbs. On the wringer body casting itself, which remained similar in external design, the reduction in weight was even more outstanding. The original iron casting weighed 15 lbs., but the aluminium-alloy pressure die-casting weighed only 4 lbs. That this loss of weight did not imply any reduction in effectiveness is demonstrated by the fact that the casting withstood without fracture a load of over 600 lbs. applied on its extremity, and this load is many times greater than that which the part has to withstand in service. These domestic wringers are called upon to withstand surprising loads at times. Cases have been known where housewives have used the wringer to climb up to reach a window, and as the wringer body is pivoted at one end only (the gear-box end) it will be appreciated that the die-cast assembly has to be quite robust! The wringer assembly is illustrated in Fig. 12.

The large castings of the wringer assembly are now of aluminium alloy, and apart from reduction in weight, they have brought considerable advantages in reduction of machining costs, accuracy of detail and matching of interdependent parts, and complete freedom from service troubles. Certain smaller components of the head assembly, such as the pressure links and the bearings, are of zinc-base alloy, as this material has a higher tensile strength than the aluminium.

The wringer gear-box shown on the left of Fig. 12 also embodies pressure die-castings but of zinc-base alloy throughout. A total of nine pressure die-castings, many of which are unmachined, go to make up the complete gear-box assembly. The main casting, shown in Fig. 13, has four inserts, which are also shown in the illustration. Two other details of the gear-box include inserts which are at least as large as the die-castings themselves. These are shown in Fig. 14.

The satisfactory results following the redesign of the wringer for pressure die-casting led to the subsequent redesign of the washing machine with which the wringer is used. This utilises no fewer than 27 pressure die-castings, including one of the largest zinc-base pressure castings produced in this country (Fig. 15)—surely a gesture of confidence on the part of the designers.

Conclusion

The discussion in the Paper will possibly indicate that, with all its advantages, die-casting will always be limited in its application; nevertheless, it is a flourishing and progressive industry, which delivers the bulk of its output to users of new amenities, where certain components have been designed specially for die-casting. Die-casting does not attempt to replace other and older industries, but has managed to establish its own special place in the sun. The industry has managed to work in friendly conjunction with its father the foundry trade and its cousin the stamping industry, and none of the three interferes with another in anything but a healthy manner.

Seventh Annual Report of the Technical Committee

(*Concluded from page* 505.)

Sub-Committee on Sands

In May, 1938, the Joint Committee on Sands was formed, and with the co-operation of Sub-Committee members considerable progress has been made, and agreement reached on recommended methods of sand testing. The Sub-Committee's work on the subject of dry-sand and oil-sand testing is still proceeding, and a number of valuable reports on various types of laboratory drying ovens for dry strength tests have been made to the Sub-Committee. Other matters which have been considered during the past year are :—(1) The accuracy of test sieves; (2) Selection of a suitable standard silica sand for testing purposes; and (3) The comparison of various types of compression strength testing machines.

Future work of the Sub-Committee will include the investigation of deformation of sand under compression. The collection of data on casting defects related to sand condition is slowly progressing, but further typical examples are still required before attempting any publication.

J. J. SHEEHAN, B.Sc.,
Convener.

Sub-Committee on Steel Castings

The heat-treatment of carbon steel castings has formed the main subject of the Sub-Committee's deliberations during the past year. During the year under review considerable progress has been made in the analysis of the data obtained from replies to a questionnaire circulated to industry, and in the drafting of a report on this work.

As a result of investigations carried out by the Sub-Committee a considerable amount of data on Izod impact testing has been obtained, and this is now being analysed. It is hoped to issue a report on valve castings on which the Sub-Committee has completed some interesting tests. The conflicting nature of the results in connection with these latter investigations makes the compilation of comprehensive reports difficult.

Useful discussions on the Ruff fluidity test and its value as a measure of control in the steelfoundry have taken place. A considerable portion of the data collected has been published in Section II, part B of the Iron and Steel Institute's Third Report on Steel Castings which was discussed at a joint meeting of the two Institutes.

C. H. KAIN,
Convener.

Atomic Patterns of Metals

(*Concluded from page* 508.)

crystal, and theoretically its atoms should re-sort themselves until it "self-anneals" to being a perfect crystal again. An alloy in one of these states of partial segregation is not in true equilibrium. Its constituent atoms should re-sort themselves into single large homogeneous crystals. In fact, a metal has no right to be strong. It is so because it has been caught in an intermediate stage before it has reached equilibrium, and although theoretically it is slowly working towards that end, the process is so slow that for practical purposes we may assume it is stable and build our bridges and machines with safety. Some recent very interesting work by Becker shows why equilibrium is so slow of attainment. A new arrangement of the atoms must start from a nucleus, and a very small nucleus of the new type of structure tends to disrupt or evaporate simply because there is not enough of it for it to be mechanically better than the existing one. We may compare it to a country in which the majority of inhabitants would like to change the form of government, but in which such a change does not take place because it is so easy to quell incipient rebellion at its source.

The Technique Indicated

It would take me too far afield if I described in detail in this lecture how it is possible to recognise these various forms of structure by X-ray analysis. As an indication of the principles involved, we may start from the case of a pure metal with a highly perfect crystalline structure. This gives diffracted beams which are sharply defined in direction, and from this arrangement we can deduce the crystalline pattern of the metal. Passing now to the case of an alloy, if this splits up into two types of crystal a double set of diffracted beams, each characteristic of the structure producing it, will be present. If the metal breaks up into a mass of small crystallites, the beams from being sharp become diffuse, and the size of the crystallites may be estimated from the breadth of the beams. If the crystallites are round, all beams are equally diffuse; if they are plate-shaped some are sharp and some diffuse, and again we can get an approximate idea of the dimensions of the plates. A random arrangement of A and B atoms on the crystal pattern gives diffracted beams like a simple crystal of α or β type; if the A B atoms take up a regular alternation A B A B A B new beams appear in intermediate positions which reveal what has happened. When the atoms segregate into certain sheets as in the age-hardening aluminium-copper alloy, certain beams are accompanied by faint "ghost" beams on either side. This is a well-known optical effect exhibited by a diffraction grating which has been ruled by a faulty engine, so that a periodic error is introduced into the spacing of the lines. These are merely a few examples; the whole story would be far too long to tell here.

I hope I have given you an indication of the possibilities opened up by X-ray analysis, and should like to end on the note with which I began. The new knowledge of the actual positions of the atoms in metals gives the pure scientist a foundation on which to base his explanations of metallic properties, and the subject of "metal physics" provides a unique opportunity for the collaboration of scientists in University and industrial laboratories.

Properties of Quenching Oils

RESULTS OF TESTS ON DIFFERENT TYPES

We reproduced last week some extracts from the Paper on "The Properties of Quenching Oils" which MR. J. A. JONES and MR. W. W. STEVENSON contributed to the Second Report of the Alloy Steel Research Committee. (This Report, it will be remembered, was presented to the recent annual meeting of the Iron and Steel Institute in London.) Below are given further extracts which disclose the results of tests on several samples of oil to determine the ten properties outlined in the earlier part of the Paper.

In Table I is given a statement of the results of properties (1) to (10) obtained on the nine samples of oil examined.

From a simple consideration of the results of laboratory chemical and physical tests, it is difficult to dogmatise in regard to the relative merits of a series of quenching oils, particularly when the oils are being used for different purposes. However, it is possible to generalise as to the likely behaviour of those oils in service.

It is obvious from the high saponification and iodine values, together with the low volatility and the behaviour after oxidation, that oil F is substantially different from the remainder of the series. This is, in fact, a sperm oil and must be regarded separately.

Also, it must be borne in mind that straight mineral oils behave differently from compounded oils in the laboratory oxidation tests; hence it is likely that a better comparison is obtained by taking the two types separately. From the saponification values it is evident that oils A, C and G are straight mineral, whilst B, D and E are compounded oils.

Considering the straight mineral oils A, C and G, it is evident that C and G have superior properties to A and there would appear to be little to choose between C and G.

Of the three compounded oils, B has greatly superior properties compared with D and E.

The foregoing comments are made from a consideration of the fact that all the oils tested have been taken from some branch of "heavy" quenching. The oils *A*, *D* and *E* are, from the results of the tests, "lighter" oils than the remainder of the series and are better suited to light work. It is obvious that very different properties are required in an oil for quenching watch springs than for an oil for use in a tyre mill or for dealing with heavy railway springs.

The sample of sperm oil is excellent for heavy work, and only shows up badly in its poor resistance to oxidation, so that great care needs to be taken in keeping tanks as cool as possible and avoiding conditions which produce thickening of the oil.

Loss of oil in quenching operations occurs by (1) volatility, (2) drip or "carry-out" and (3) carbonisation. Volatility is a function of the light fractions present in the oil, "carry-out" is connected with the viscosity of the oil, whilst carbonisation is closely allied to resistance to oxidation. For maximum efficiency for each particular quenching purpose, it is necessary to arrive at a compromise between the volatility and viscosity. For low carbonisation, the oil should contain the minimum of fatty oil or the conditions of the quenching shop should be such as to reduce the possibilities of oxidation of the oil to a minimum.

In regard to specific heat, the three mineral oils (*AN*, *C* and *G*) give specific-heat/temperature curves of similar shape, the specific heat rising with the temperature. The oil used *AO* has a lower specific heat than the corresponding unused oil *AN*, the difference being most marked at the higher temperatures.

The sperm oil (*F*) shows a maximum in the specific heat at about 80 to 85 deg. C.

The specific heat of each of the compounded oils (*B*, *D* and *E*) rises with the temperature, but the shapes of the curves differ to some extent. It is interesting to note that the specific heat of the used compounded oil *BO* is slightly greater than that of the corresponding unused oil *BN*, whereas that of the mineral oil *A* is less after use.

Comparison of the two used oils with the samples of new oil of the same qualities indicates the changes in properties to be expected with continued use. The flash point and viscosity of the used oil are higher, the coke number, tendency to sludge and thermal conductivity are higher, the saponification value and acid value are higher, whilst the volatility is slightly lower than that of the new oil.

TABLE I.—*Properties of the Quenching Oils Examined.*

Oil sample :	AN.	AO.	BN.	BO.	C.	D.	E.	F.	G.
Saponification value, mg. KOH per grms.	Nil	4.8	7.21	10.09	1.4	3.8	4.36	143.0	Negligible
Acidity (acid value), mg. KOH per grms.	0.38	2.06	0.62	4.65	0.14	0.71	0.60	5.10	Negligible
Iodine value (Wijs on 5 grms.)	6.0	6.0	7.0	7.0	5.0	5.0	6.0	90.0	3.0
Flash point (Pensky-Marten closed), deg. F.	305	325	350	360	410	335	330	475	400
Flash point, open, deg. F.	330	345	385	390	425	355	350	505	425
Specific gravity at—									
60 deg. F.	0.884	0.894	0.891	0.892	0.867	0.903	0.902	0.888	0.866
75 deg. F.	0.880	0.886	0.885	0.887	0.860	0.898	0.897	0.883	0.861
100 deg. F.	0.872	0.877	0.875	0.878	0.852	0.889	0.887	0.873	0.852
125 deg. F.	0.865	0.869	0.866	0.870	0.843	0.881	0.878	0.864	0.843
150 deg. F.	0.856	0.861	0.857	0.861	0.835	0.872	0.869	0.855	0.835
175 deg. F.	0.846	0.852	0.849	0.852	0.826	0.864	0.861	0.846	0.826
200 deg. F.	0.836	0.844	0.840	0.843	0.817	0.856	0.851	0.837	0.817
Viscosity (Redwood No. 1), sec., at—									
60 deg. F.	265	313	287	347	391	289	217	208	370
75 deg. F.	180	209	184	208	249	180	145	141	230
100 deg. F.	97	108	100	110	130	97	80	95	130
125 deg. F.	62	69	65	70	82	63	55	67	80
150 deg. F.	49	53	51	53	59	49	43	53	59
175 deg. F.	41	43	42	43	48	42	38	45	48
200 deg. F.	37	38	38	39	42	38	34	40	41
Volatility. Loss by weight, per cent.	21.5	17.5	19.5	18	8	26.5	26.5	2.0	9
Tendency to sludge (B.S.S. 148–1933), per cent.	1.34	2.6	1.52	3.58	0.64	1.77	1.51	0.05	0.85
Viscosity, kinematic (Stokes), at 100 deg. F.	0.235	0.267	0.253	0.271	0.330	0.231	0.185	0.229	0.324
Ramsbottom coke number	0.11	0.47	0.11	0.62	0.12	0.19	0.10	0.24	0.07
Properties after Air Ministry oxidation test—									
Viscosity, kinematic (Stokes), at 100 deg. F.	0.335	0.436	0.432	0.934	0.500	0.606	0.416	2.704	0.599
Ramsbottom coke number	1.45	1.77	2.02	2.41	0.98	2.49	2.30	2.03	1.26
Ratio of viscosity after to that before oxidation (Air Ministry)	1.43	1.63	1.71	3.45	1.51	2.62	2.25	11.80	1.85
Increase in coke number	1.34	1.30	1.91	1.79	0.86	2.30	2.20	1.79	1.19

Correspondence

[We accept no responsibility for the statements made or the opinions expressed by our correspondents.]

The Annual Cricket Match

To the Editor of THE FOUNDRY TRADE JOURNAL.

SIR,—The full details of the arrangements for the annual cricket match between the Institute of British Foundrymen and the Works Management Association are now available. The match will take place on the grounds of H. P. Bulmer & Company, Limited, Hereford, on Sunday, June 25.

Lunch may be obtained at the Green Dragon Hotel, Hereford, at 1 p.m., and tea will be served in the Club Pavilion at 5 p.m. Play will commence at 2.30 p.m. The cricket ground is about one mile out of Hereford, on the Hay Road.

Will those who intend to join the party for lunch be good enough to advise the undersigned as early as possible? For general information, there will be tennis courts and a bowling green available, and tennis and bowls may be played.—Yours, etc.,

J. E. HURST.

Darlaston Blast Furnaces,
Darlaston.
June 12, 1939.

World's Largest Ingot Mould

We are indebted to Mr. Pat Dwyer, Engineering Editor of "The Foundry," for pointing out that a large ingot mould was cast early in 1927 by the Bethlehem Steel Company, Bethlehem, Pa., for use in its own plant. It was poured from three ladles in 14 minutes, and 387,590 lbs. of iron, or 193.79 tons, were required for casting, gates and head. The cleaned casting weighed 382,000 lbs., or 191 tons. Even allowing for the discrepancy between the (presumably) British 170 long tons and the American 193.79 short tons, the Bethlehem casting still appears to hold the world ingot mould weight record. Thus the statement made on page 392 of our issue of May 11, that the 170-ton mould made by Brightside Foundry & Engineering Company was the largest in the world, cannot be substantiated.

The Week's News in Brief

Trade Talk

THE TOTAL NUMBER of steel air-raid shelters delivered to householders to the end of May was 571,545.

A FURTHER LARGE EXPANSION in the form of a completely new machine shop is now almost completed at the Loughborough works of the Brush Electrical Engineering Company, Limited.

THE ANNUAL MEETING of the Vereins Deutscher Emailfachleute (German Vitreous Enamellers' Association) will be held in the local technical school at Köthen from June 18 to 24.

STEEL & COMPANY, LIMITED, engineers and ironfounders, of Sunderland, have taken over the site of the old E.G.I.S. Shipyard at Pallion, Sunderland, for the erection of a factory for making mobile cranes and steel supports for basement air-raid shelters.

As the result of negotiations between the Engineering Employers' Federation, the Crucible Steel Makers' Association and the Sheffield Rollers and Tilters' Association on one side, and the Amalgamated Engineering Union, the Foundry Workers' Union and the Federation of Engineering and Shipbuilding Trades on the other, Sheffield workers in the trades concerned will receive an extra 2s. a day.

THE BRITISH ALUMINIUM COMPANY, LIMITED, are transferring their branch office and aluminium warehouse from 25/29, Pancras Road, London, N.W.1, as from July 1 next, to more spacious premises at Park Avenue, North Circular Road, N.W.10. Ample stocks of aluminium and its light alloys, in ingot and semi-manufactured forms, will be maintained at this depôt, which will be under the management of Mr. W. J. Allen.

H. G. SOMMERFIELD, LIMITED, are now comfortably settled in their new centralised premises at 44, St. Pancras Way, London, N.W.1. The buildings incorporate a compact block of administrative offices, drawing office, a works well capable of dealing with the increasing output of foundry equipment, sand blast and dust-extracting plant, and a stores (double the capacity of the old stores) served by private railway siding.

IT IS REPORTED that two Sheffield steel firms have been making inquiries about the 14-acre site of the former Cammell Laird iron and steel works at Penistone. The offices are still in existence, although all other buildings have been demolished. The works were closed in 1930 but in 1935 David Brown and Sons, the Huddersfield gear manufacturers, purchased the site and buildings on the new side of the works, but did not take over the site of the old side, which was divided by the railway.

SMITH'S DOCK COMPANY, LIMITED, have booked a contract to build four ships of 3,400 tons each at their River Tees Dockyard for the Prince Line, Limited. Barclay, Curle & Company, Limited, Whiteinch, Glasgow, have obtained an order from the British India Steam Navigation Company for a cargo vessel of about 6,600 tons gross. William Pickersgill & Sons, Limited, Sunderland, have laid the keels of three vessels for British owners, ordered recently. Sir James Laing & Sons, Limited, Sunderland, have received orders from Ropner & Company, West Hartlepool, for two motorships of 9,500 tons deadweight. The engines will be supplied by J. G. Kincaid & Company, Limited, Greenock. Shipbuilders in Scotland have booked orders since the end of March for approximately 60 merchant vessels totalling over 300,000 tons gross.

Applications for Trade Marks

The following list of applications to register trade marks has been taken from the "Trade Marks Journal":—

"BIRLEC."—Machinery, belt conveyors, etc. Birmingham Electric Furnaces, Limited, Birlec Works, Tyburn Road, Erdington, Birmingham.

"HASTELLOY."—Alloys of non-precious metals. Haynes Stellite Company, c/o Marks & Clerk, 57/58, Lincoln's Inn Fields, London, W.C.2.

Personal

SIR ROBERT HADFIELD and MR. HARRY BREARLEY were made honorary freemen of the City of Sheffield last week.

LORD CATTO has been elected a director of the International Nickel Company of Canada, Limited, in succession to the late Sir Robert Mond.

MR. GORDON L. PADLEY has resigned his directorships of Walter Spencer & Company, Limited, and of Marshall, Sons & Company (Successors), Limited.

MR. E. LONGDEN, foundry manager of Craven Bros. (Manchester), Limited, is now an Associate Member of the Institution of Mechanical Engineers.

RETIRING AFTER 20 YEARS' SERVICE with Glenfield & Kennedy, Limited, Kilmarnock, Mr. John Elliot has received a hide chair from his fellow-workers. The gift was presented by Mr. Greaves, head foreman of the patternshop.

MR. OLIVER SMALLEY, managing director of the International Meehanite Metal Company, Limited, London, and President of the Meehanite Research Institute of America, Inc., Pittsburgh, Pa., whose name appeared in the list of Birthday Honours as a recipient of the O.B.E., will arrive in London on June 19, and will spend about two months visiting various Meehanite manufacturers in England, on the Continent, and in Norway and Sweden. Mr. Smalley is British Consul at Pittsburgh.

Company Reports

Turner & Newall, Limited.—Interim dividend of 3¾ per cent.

Glacier Metal Company, Limited.—Dividend of 6 per cent. on the ordinary shares for the year ended February 28.

Cannon Iron Foundries, Limited.—Dividend on the 5½ per cent. preference shares for the half-year ending June 30, 1939.

Stanton Ironworks Company, Limited.—Final ordinary dividend of 6 per cent., making 10 per cent. for the year ended March 31.

Keith Blackman, Limited.—Net profit for year to March 31 last, £32,528; dividend of 15 per cent. on the ordinary shares.

Triplex Foundry, Limited.—Profit for year ended March 31, £12,466; final dividend of 5½ per cent., making 8 per cent.; carried forward, £5,432.

Anderston Foundry Company, Limited.—Profit for the year ended March 31, £11,835; brought in, £1,971; dividend of 10 per cent.; carried forward, £7,207.

F. H. Lloyd & Company, Limited.—Net profit for year to March 31 last, £47,871; final dividend on the ordinary shares of 7 per cent., making 10 per cent. for the year.

British Oxygen Company, Limited.—Dividends on the 6½ per cent. cumulative preference and 5 per cent. cumulative second preference stock for the half-year ending June 30.

Barrow Hæmatite Steel Company, Limited.—Profit for the year ended December 31 last, after payment of interest charges, £55,994; brought in, £12,039; to general reserve, £50,000; carried forward, £18,033.

J. Stone & Company, Limited.—Net profit for 1938, after providing for income-tax, N.D.C., and contingencies, £208,678; brought in, £212,506; dividend on the ordinary shares of 27½ per cent., tax free; carried forward, £217,073.

Fairbairn Lawson Combe Barbour, Limited.—Trading profit for the year ended March 31, £77,472; net profit after interest charges, depreciation, income-tax, etc., £42,339; brought in, £50,071; dividend on the non-cumulative first preference shares of 5 per cent.; to contingency reserve, £18,000; carried forward, £81,985.

Morgan Crucible Company, Limited.—Profit for the 15 months ended March 31 last, £584,406; brought in, £104; taxes, £157,980; preference dividends, £98,736; interest on 5 per cent. obligations, £15,646; final dividend of 1s. 2d. per £ on the ordinary stock, making 1s. 11d. for the 15 months; applied in the capitalisation of 5 per cent. obligations to be retained for employment in the business, £161,850; carried forward, £362.

Obituary

MR. A. LYNDON LAWRENCE, managing director of Dewrance & Company, engineers, has died.

MR. HORACE MOORE THORNTON, a managing director of Radiation, Limited, and of Richmonds Gas Stove Company, Limited, and other companies, has died at his home at Purley, Surrey, at the age of 67.

MR. GEORGE ALFRED CLOSE, a director of the Rochdale Aluminium & Bronze Foundry Company, Limited, of John Downham & Company, Limited, of Bury, and of the Moorlands Engineering Company, Limited, died at Manchester last week. He was 63 years of age

MR. L. A. G. LEPERSONNE, chairman of the Power Plant Company, Limited, West Drayton, Middlesex, died on June 2 after a short illness. He was a Freeman of the City of London and held several Belgian honours, including Chevalier de l'Ordre de Leopold and Chevalier de l'Ordre de la Couronne.

Patent Specifications Accepted

The following list of Patent Specifications accepted has been taken from the "Official Journal (Patents)." Printed copies of the full Specifications are obtainable from the Patent Office, 25, Southampton Buildings, London, W.C.2, price 1s. each. The numbers given are those under which the Specifications will be printed and abridged, and all subsequent proceedings will be taken.

502,832. RUBISSON, G. A. Manufacture of solid materials by melting and then cooling while under the influence of centrifugal force.

502,942. FREYN ENGINEERING COMPANY. Blast furnaces.

503,008. MOND NICKEL COMPANY, LIMITED. Electrodeposition of metals on alloys containing chromium.

503,050. JUNGHANS, S. Apparatus for the continuous casting of castings with continuous longitudinal hollow spaces or of several castings in one chill-mould.

503,070. BRITISH THOMSON-HOUSTON COMPANY, LIMITED. Manufacture of wire.

503,131. EVANS, O. (Dortmund-Hoerder Hüttenverein Akt.-Ges.). Method of reducing the amount of manganese lost in the production of Thomas steel.

503,194. STEVENS, A. H. (Byers Company, A. M.). Methods of and apparatus for making wrought iron.

503,397. PETERSSON, H. Hard metal alloys.

503,740. KOHLE UND EISENFORSCHUNG GES. Machines for testing the physical qualities of material.

503,794. UDY, M. J. Manufacture of ferro-chromium.

503,929. SIEMENS & HALSKE AKT.-GES. Iron alloys for permanent magnets.

504,097. BERGHAUS, B. Annealing and melting furnaces, working under reduced pressure.

504,122. KALLING, B. M. S. Decarbonisation of carbon-containing iron and ferro-alloys.

504,224. SANDVIKENS JERNVERKS AKTIEBOLAG. Alloy steel.

504,371. ELECTRO METALLURGICAL COMPANY. Production of magnetisable steel sheets.

504,435. FIDES GES. FUR DIE VERWALTUNG UND VERWERTUNG VON GEWERBLICHEN SCHUTZRECHTEN. Permanent magnets and processes for the production thereof.

504,588. STEELE, H., and GOSS, W. M. Methods of and apparatus for treating readily oxidisable molten metal to produce a continuous solid strip therefrom.

504,793. RAMSEY, A. R. J. (Schoeller Werk Komm-Ges.). Apparatus for coating the inner surfaces of iron tubes with a non-ferrous metal.

505,251. COLBECK, E. W., and IMPERIAL CHEMICAL INDUSTRIES, LIMITED. Manufacture of high chromium iron and steel.

Forthcoming Event

JUNE 28.

Manchester Association of Engineers:—Works visit to the Churchill Machine Tool Company, Limited, Broadheath, near Manchester, at 2.30 p.m.

Raw Material Markets

There appears to have been some improvement in the demand for foundry pig-iron, but this section of the iron and steel industry continues to be rather quiet and the current outputs, relatively low as they are in all districts, are more than sufficient to meet consumers' requirements. Other descriptions of iron and also steel are well taken up, and difficulties are presenting themselves sometimes as far as the satisfaction of commercial work is concerned, owing to the insistent demand for material for Government work.

Pig-Iron

MIDDLESBROUGH.—Several of the local founders report increased order-books, but the position still leaves much to be desired. No announcement has yet been made with regard to future prices, and although it is unlikely that there will be any reduction on existing quotations, buyers will not yet purchase far forward. A quiet tone continues to rule in the hematite section of the market, as there is no disposition to buy at present in view of the reduction of 5s. per ton which will be applied to prices at the end of the month. Meanwhile, consumers are concentrating on using up their stocks. Producers have adequate stocks on hand and some of them have found it necessary to curtail their make for the time being. It is expected that there will be a return to normal activity early in July, when heavy tonnages are likely to change hands.

LANCASHIRE.—Despite the fact that it might well be to their advantage, consumers are not buying forward, as they think that there is still the possibility of an early reduction in prices. In authoritative circles, however, the view is held that a change in quotations will not be in a downward direction. The uncertainty is holding up trade to some extent and an early decision would be welcomed. Consumers who have pressing requirements to meet are merely satisfying these and only small tonnages are being negotiated. There has been a slight change for the better among light-castings and jobbing foundries in this area, but neither of these sections shows any indication of returning to the activity which might be expected at this time of the year. Hematite users, too, are restricting their purchases to small parcels, as current prices will be lowered by 5s. per ton as from July 1.

MIDLANDS.—A quiet tone continues to prevail in the market for high-phosphorus iron, and, with many consumers still working short time, there are few signs of any change in the outlook. Some consumers have been accumulating stocks recently in view of the possibility of higher prices coming into operation shortly, but, on the whole, business has been very dull for some time past. The general opinion with regard to the future trend of prices is that there will be no change when producers review the position. The demand for low-phosphorus iron continues to be maintained at a good level, and the heavy engineering and machine-tool concerns are taking up heavy tonnages. There has been rather less business in hematite since the makers announced that quotations would be lowered by 5s. per ton as from July 1, but it is expected that trade will revive then, as many consumers are working to capacity.

SCOTLAND.—Slightly better order-books are reported among several of the local founders, but the demand for iron continues to be at a comparatively low level. Stocks at the makers' works are large and consequently surprise was caused recently by the arrival at Glasgow of a shipment of 500 tons of Australian foundry iron. Both hematite and basic iron are in heavy request by the steelworks in this area, which are working to capacity.

Coke

Trade in foundry coke is very active, and good supplies are being called for by the foundries. In the circumstances, it is practically certain that there will be no reduction in the existing minimum price of 50s. 6d. per ton, delivered Birmingham and district, for both Durham and Welsh coke at the end of the month.

Steel

The output of steel in May totalled 1,218 100 tons, which is 40,009 tons above the highest figure previously recorded for any single month. This figure was achieved in May despite the Whitsun stoppage which was observed at certain works. During the month it is estimated that the steel industry was operating at around 93 per cent. of present operative capacity. The demand for all descriptions of steel continues to be very heavy. In some cases re-rollers are having to curtail operations owing to the absence of adequate supplies of raw material. Buyers of sheets are now having difficulty in placing new orders, as makers are booked up over some months to come, especially those engaged on the production of shelters under the air-raid precautions programme.

Scrap

There is still a keen demand for scrap suitable for steel plants and the available supply generally is insufficient to satisfy the requirements of the works. Although supplies of scrap have recently arrived from the United States, imports have so far been totally inadequate and more foreign scrap will have to be secured if the shortage in this country is to be relieved to any extent.

Metals

Trade in non-ferrous metals has been rather dull of late. Buyers have displayed little interest in new business, while there have been fewer speculative orders also.

Copper.—Business has ruled quiet and no outstanding feature has been apparent during the past few days. Conditions still do not inspire confidence in forward positions and trade is generally restricted to prompt tonnages. Demand on Japanese account has been distinctly quiet, while little business is now emanating from Russia. A brighter tone has prevailed on the United States copper market, but the outlook for consumption in that country is not very promising. Recent strike trouble at the motor works and the continued political differences have tended to restrict business.

Reference to the steady progress achieved by the Copper Development Association was made by Mr. D. Owen Evans at the annual meeting of the Association in London last week. He spoke of the satisfactory position in which it had now become established as a central bureau of information for the copper industry. The market for copper during the past year had been relatively steady, and a continuance of such stability would be of great benefit to industry and would assist development work. Mr. Evans said that the Association had been in existence for nearly six years and the success which it had achieved suggested that it might become a permanent feature of the copper industry. It was satisfactory that its existence had been assured for at least another five years.

Metal Exchange quotations were as follow :—

Cash.—Thursday, £42 2s. 6d. to £42 3s. 9d.; Friday, £41 17s. 6d. to £41 18s. 9d.; Monday, £41 12s. 6d. to £41 13s. 9d.; Tuesday, £41 7s. 6d. to £41 8s. 9d.; Wednesday, £41 17s. 6d. to £42.

Three Months.—Thursday, £42 10s. to £42 11s. 3d.; Friday, £42 3s. 9d. to £42 5s.; Monday, £41 18s. 9d. to £42; Tuesday, £41 15s. to £41 16s. 3d.; Wednesday, £42 3s. 9d. to £42 5s.

Tin.—The demand for this metal has continued to be rather quiet and recent business has involved only small tonnages. At the meeting of the Billiton Company at Amsterdam last Friday, the chairman, Baron van Tuyll van Serooskerken, said that there were signs of a revival in the tin industry, which gave rise to the hope that an increase of export quota would soon be submitted. Although the buffer stock organisation had been operated for only a short period, it might be said so far that the executive body of the pool had succeeded during the past eight months in keeping prices within the fixed margin. The speaker said that the metal had shown remarkable resistance to political upheavals.

The Bolivian Government has recently issued a decree seizing all foreign exchange received for minerals exported, and it was feared that this step might lead to expropriation of the tin-mining industry. But Government spokesmen have since stated that this will not be so.

The International Tin Committee met in Paris yesterday (Wednesday) for the purpose of deciding the export quota for the third quarter of the year, and the uncertainty prevailing prior to their decision has been largely responsible for the quietness of business of late. The Committee decided to raise the existing quota by 5 per cent. to 45 per cent. This was in accordance with general expectations, although it had been thought likely in some quarters that the quota might have been increased by as much as 10 per cent. Since the 40 per cent. quota came into operation at the beginning of April, visible supplies of tin have been substantially reduced, thus lowering supplies not held by the buffer pool to small proportions.

Official quotations were as follow :—

Cash.—Thursday, £225 10s. to £225 15s.; Friday, £225 to £225 5s.; Monday, £224 5s. to £224 10s.; Tuesday, £224 10s. to £224 15s.; Wednesday, £227 10s. to £227 15s.

Three Months.—Thursday, £223 to £223 5s.; Friday, £222 10s. to £222 15s.; Monday, £222 to £222 5s.; Tuesday, £222 5s. to £222 10s.; Wednesday, £225 to £225 5s.

Spelter.—While consumption of this metal is believed to have been well maintained, there has been little buying recently by consumers. It is understood that tentative negotiations for the re-establishment of the International Zinc Cartel are proceeding, but no meeting of producers has yet been convened.

Daily market prices :—

Ordinary.—Thursday, £14 1s. 3d.; Friday, £14 2s. 6d.; Monday, £14 2s. 6d.; Tuesday, £13 18s. 9d.; Wednesday, £14.

Lead.—There has been a decline in speculative interest in this metal and the tone of the market has eased to some extent. Business in Europe is fairly well maintained.

Day-to-day quotations :—

Soft Foreign (Prompt).—Thursday, £14 7s. 6d.; Friday, £14 8s. 9d.; Monday, £14 7s. 6d.; Tuesday, £14 6s. 3d.; Wednesday, £14 11s. 3d.

Scrap.—A welcome improvement has been noticeable in the scrap market and the demand has shown a considerable expansion. Consumers have come into the market for quite substantial tonnages.

Approximate selling prices for old metal :—New aluminium cuttings, £69; rolled, £57; cast, £30 to £35; foil, £80. Copper, £38 to £43; braziery, £36. Brass (clean), £22 to £25. Zinc, £10. Lead, £13 10s. Gunmetal, £38.

Contracts Open

Dublin, July 15.—Supply and erection of overhead travelling cranes and fuel-handling cranes, for the Electricity Supply Board. The Chief Design Engineer, Electricity Supply Board, 37, Merrion Square, Dublin, C.18. Fee £2 2s., returnable.

Hitchin, June 20.—Construction of 3,200 yds. of 7, 6, 4 and 3 in. cast-iron mains, etc., for the Urban District Council. D. Balfour & Sons, civil engineers, 47, Victoria Street, London, S.W.1. (Fee £5, returnable.)

Ince, June 17.—Iron and steel, castings, lead pipes and fittings, etc., for six months, for the Ince-in-Makerfield Urban District Council. Mr. A. F. Howgate, clerk, Council Offices, Ince.

Kirkcaldy, June 17.—Supply and erection of two 1,000,000 cub. ft. per diem water-cooled condensers; 2,000,000 cub. ft. per day Livesey washer; two 1,000,000 cub. ft. per day static washers, all complete with inlet, outlet, and by-pass connections, for the Town Council. The Gas Engineer, 28, Links Street, Kirkcaldy.

Plymouth, July 1.—36-in. non-return valve for circulating water system; 30-in. and 36-in. bore cast-iron pipes for circulating wate. system; supply and erection of desuperheater and reducing valve equipment; supply and erection of high-pressure steam and water pipework; supply and erection of distribution switchgear, starters, and motors for boiler and turbine auxiliaries, for the Electricity Supply Depôt. The City Electrical Engineer, Armada Street, Plymouth.

Santiago, July 4.—Various foundry material and supplies, *viz.*, metal ingots (antimony, aluminium, phosphor, copper, tin, lead and zinc), manganese iron, etc., for the Chilean State Railways Administration. (D.O.T. reference: T. 22.811/39.)